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PANEL REVIEW OF THE SEMI-AUTOMATED FORCES

Rodney A. Brooks  
Bruce G. Buchanan  
Douglas B. Lenat  
David M. McKeown, Jr.  
J. D. Fletcher

September 1989

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PANEL REVIEW OF THE SEMI-AUTOMATED FORCES

Rodney A. Brooks  
*Massachusetts Institute of Technology*

Bruce G. Buchanan  
*University of Pittsburgh*

Douglas B. Lenat  
*Microelectronics and Computer Technology Corporation*

David M. McKeown, Jr.  
*Carnegie Mellon University*

J. D. Fletcher  
*Institute for Defense Analyses*

September 1989



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## ABSTRACT

This report documents a review of the technical approach used to develop the semi-automated forces (SAFOR) portion of DARPA's Advanced Simulation Technology Program. The review was conducted in August 1989 by an independent panel of four computer scientists whose comments are presented and summarized. The panel concluded that (1) the SAFOR development is work of high quality; (2) the suite of hardware being used is non-optimal, but the effort to change it is not currently justified, (3) conversion of the software to another language is not currently justified, (4) the objectives of the SAFOR development should be explicated and made more specific, (5) some limited measures should be taken in the short term to improve the adaptability of the SAFOR, but more substantial measures should be pursued in a longer term research effort, (6) more and better tools for users of the SAFOR should be developed, (7) more systematic test and evaluation procedures should be incorporated in the SAFOR effort.

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## INTRODUCTION AND SUMMARY

On 26 June 1989 the Defense Advanced Research Projects Agency (DARPA) requested that the Institute for Defense Analyses (IDA) conduct a peer review of the technical approach being used to develop the Semi-Automated Forces (SAFOR) for DARPA's Advanced Simulation Technology (AST) Program. This review was held on 10-11 August 1989 at the Advanced Simulation Technology Facility in Rosslyn, Virginia.

The review panel consisted of the following members:

Rodney A. Brooks  
Associate Professor  
Massachusetts Institute of Technology

Bruce G. Buchanan  
Professor of Computer Science, Medicine, and Philosophy  
University of Pittsburgh

Douglas B. Lenat  
Principal Scientist, Artificial Intelligence Project  
Microelectronics and Computer Technology Corporation

David M. McKeown, Jr.  
Research Computer Scientist  
Carnegie Mellon University

Brief biographical sketches for the panel members are provided in Appendix A.

About two weeks prior to the review meeting, each panel member received a "read-ahead" package that provided information on the simulator network (SIMNET) and the development of the SAFOR. The documents included in this package are listed in Appendix B.

In general, the panel was to consider the following question:

Is there anything in the development of the SAFOR that should be done differently to better meet the goals of the SIMNET, AST, and Advanced Battle Simulation programs?

The agenda for the review on 10-11 August was flexible, but it included four basic activities:

Orientation, panel responsibilities, SIMNET and AST objectives and technologies presented by LTC Shiflett and program staff.

Description and discussion of SAFOR objectives, development, and technical approach by Bolt Beranek and Newman (BBN) staff (Duncan Miller, Stephen Downes-Martin, and Stephen Deutsch). The briefing materials used by BBN for this portion of the review are provided in Appendix D.

Discussion and review of SAFOR technical approach by the panel.

Debriefing by the panel for DARPA and Army representatives on the SAFOR technical approach.

After these meetings, members of the panel documented their impressions of the SAFOR program and its technical approach. A brief summary of their comments follows:

1. Quality of the work. Three of the four panelists commended the SAFOR development as high quality work, done by good people. All panel members concurred with this point of view which was expressed in their debriefing on 11 August. One panelist mentioned "edginess" in the SAFOR staff -- a concern that their good work completed in limited time with limited resources would be rewarded by even greater challenges from the sponsor.

2. Hardware. Three of the four panelists stated that the choice of hardware for the project is non-optimal. However, all three also recommended against any change to new hardware since that would incur high costs that would not be compensated for by new capabilities or efficiencies. They also suggested that changes in the state of the art and the scale of the SAFOR could shift the balance of the trade-off.

All four noted that 30-34 percent of the Butterfly computations remains undetermined. These computations will impact the capacities of the existing system to support a larger scale SAFOR. The panelists suggested that these computations should be better understood before scaling up the SAFOR using the current hardware.

3. Software. Two of the panelists recommended that conversion of the SAFOR software to Ada be strongly resisted. One recommended that conversions to LISP be similarly resisted. They viewed the current practice of programming in C to be the best compromise choice.

4. Objectives. All four noted uncertainty in the objectives for the SAFOR. On one hand, there is some value in this uncertainty since it allows flexibility. On the other hand, design decisions require definite objectives. The impression of the panel appears to be that the balance has shifted too far in the direction of uncertainty and that more explicit direction is needed before scaling up the SAFOR. Specifically, more certainty is needed concerning (1) whether the SAFOR is to be used for training, equipment capabilities testing, or doctrine development, and (2) if training, who is to be trained to do what. More certainty will help determine (1) the granularity of representation needed for real time play and after-action review and analyses, (2) the positions that must be kept manned, and (3) the hardware and software architecture of the SAFOR.

Two of the panelists cautioned that attempts to scale up the SAFOR beyond a currently undefined level may be making too much of a good thing -- it may extend the technology beyond its appropriate application limits.

5. Adaptability. Three of the panelists discussed "learning" by SAFOR units -- the ability to continually adjust tactics in the iterative manner seen in fully manned engagements. The panelists suggested that more could and should be done to enhance this capability in the short term through, for instance, parameter adjustments and incorporation of the route planning capabilities emerging from other R&D projects. However, adaptability is fundamentally a long-term goal deserving support as a research project. One long-term approach might be to incorporate more real world knowledge in the SAFOR.

6. Modifiability and Transfer. Two of the panelists recommended that more tools be developed to increase the capabilities of users to modify system configuration and data structures. One panelist stressed the need for better system documentation to better support development of the system, improved transfer to its eventual maintainers, and training for new users.

7. Assessment. Two of the panelists recommended that more systematic test and evaluation of the SAFOR be planned and provided. The scheduled proof of principle tests are helpful, but less dramatic, smaller scale, and more frequent test and evaluation should be encouraged and supported.

The comments of the panelists in their own words are clear and to the point. They are provided in Appendix C as a more comprehensive summary of panel findings.



Recommendations based on panelists' comments might include the following:

1. The accomplishments of the development team should not be met with greater demands and fewer resources. A mechanism should be provided for continuity in the current development team.
2. An analysis of the hardware requirements for the SAFOR should be undertaken assuming several scenarios of growth and scale.
3. The objectives for the SAFOR should be clarified. The eventual scale -- or alternatives for the scale -- of the SAFOR should be clarified.
4. A short-term effort should be made to improve the adaptability of the SAFOR units. A long-term research effort should also be undertaken to improve their adaptability.
5. Documentation of the SAFOR should be improved and better tools for users should be developed.
6. Systematic procedures for more frequent test and evaluation should be incorporated into the SAFOR development program.
7. The involvement of this panel in the SAFOR development should be encouraged and continued.

Other recommendations may well occur to readers of the panelists' comments.

**APPENDIX A**  
**BIOGRAPHICAL SKETCHES OF PANEL MEMBERS**

## APPENDIX A

### BIOGRAPHICAL SKETCHES OF PANEL MEMBERS

#### RODNEY A. BROOKS

Rodney Brooks is an Associate Professor, Department of Electrical Engineering and Computer Science at the Massachusetts Institute of Technology. His undergraduate training was in mathematics. He received the Ph.D. in Computer Science from Stanford University in 1981. He has held research positions at Carnegie Mellon University and MIT and faculty positions at Stanford University and MIT. His current research is in the MIT Artificial Intelligence Laboratory where he works on completely autonomous mobile robots with particular emphasis on vision for navigation and the decomposition of control systems.

He built the ACRONYM vision system as part of his doctoral work at Stanford. He worked on the definition of Common LISP and its first supercomputer implementation at Lawrence Livermore Laboratories. He is the author of *Model-Based Computer Vision* and *Programming in Common LISP* and a co-founding editor of the *International Journal of Computer Vision*. He is a member of AAI, AAAS, ACM, and IEEE.

#### BRUCE G. BUCHANAN

Bruce Buchanan is a Professor of Computer Science, Medicine, and Philosophy at the University of Pittsburgh and Co-Director of the Center for Parallel, Distributed, and Intelligent Systems. He received the B.A. degree in mathematics from Ohio Wesleyan University and the M.S. and Ph.D. degrees in philosophy from Michigan State University. Prior to joining the faculty at the University of Pittsburgh, he was a Professor of Computer Science Research and Co-Director of the Knowledge Systems Laboratory at Stanford University. His research interests are in artificial intelligence, with particular emphasis on intelligent computer programs that assist scientists and physicians, including programs and methods for knowledge acquisition and machine learning, scientific hypothesis formation, and construction of expert systems.

He is a Senior Fellow in the Center for the Philosophy of Science at the University of Pittsburgh and a member of the Scientific Advisory Board for Oak Ridge National

Laboratories Energy Division. He was a principal in the design of the DENDRAL, Meta-DENDRAL, MYCIN, E-MYCIN, and PROTEAN systems. He is Secretary-Treasurer of AAI, a fellow in the College of Medical Informatics, and an editor of *Artificial Intelligence*, *Machine Learning* and *Knowledge Acquisition*.

#### **DOUGLAS B. LENAT**

Douglas Lenat is the Principal Scientist of the Microelectronics and Computer Technology Corporation's Artificial Intelligence Project. He received the Ph.D. degree in Computer Science from Stanford University in 1976. Prior to joining MCC, he was a professor in the Computer Science Departments of Carnegie Mellon University and Stanford University. He is also a founder of Teknowledge, Inc. His research interests concern creative discoveries that can be made by computer programs and the development of common sense behavior in computer programs using real world information contained in very large data bases.

In addition to over 40 published papers, he is the author of *Knowledge Based Systems in Artificial Intelligence* and *Building Expert Systems*. His thesis work concerning creative discoveries in mathematics that could be produced by a computer program earned him the IJCAI Computers and Thought award in 1977. In 1984, he was named as one of America's 100 brightest scientists under the age of 40.

#### **DAVID M. MCKEOWN, JR.**

David McKeown is a Research Computer Scientist in the School of Computer Science at Carnegie Mellon University. He received the B.S. degree in Physics and the M.S. degree in Computer Science from Union College. Prior to joining the faculty at CMU, he was a researcher, beginning in 1975. He has also been a Research Associate at George Washington University, a Member of the Technical Staff at NASA Goddard Space Flight Center, and an instructor at Union College. His research interests are in image understanding for aerial photo-interpretation, digital mapping and image/map data base systems, computer graphics, and artificial intelligence.

He has been the principal investigator on research programs sponsored by the U.S. Army Engineering Topographic Laboratories, the Defense Mapping Agency, the Air Force Office of Scientific Research, and the Defense Advanced Research Projects Agency. He is a member of AAI, ACM, IEEE, and the American Society for Photogrammetry and Remote Sensing.

**APPENDIX B**  
**READ-AHEAD DOCUMENTS**

## APPENDIX B

### READ-AHEAD DOCUMENTS

Abrett, G., Burstein, M., Deutsch, S. *TARL: Tactical Action Representation Language -- An Environment for Building Goal Directed Knowledge Based Simulations* (Report No. 7062). Cambridge, MA: BBN Systems and Technologies Corporation, 5 June 1989.

Ceranowicz, A., Downes-Martin, S., Saffi, M. *SIMNET Semi-Automated Forces Version 3.0: A Functional Description* (Report No. 6939). Cambridge, MA: BBN Systems and Technologies Corporation, 6 March 1989.

Ceranowicz, A., Downes-Martin, S., Saffi, M. *SIMNET Semi-Automated Forces Version 3.0: Implementation Issues* (Report No. 6940, Revised). Cambridge, MA: BBN Systems and Technologies Corporation, 27 October 1988.

MacLaughlin, D.M. and Shaked, V. *Natural Language Text Generation in Semi-Automated Forces* (Report No. 7092). Cambridge, MA: BBN Systems and Technologies Corporation, 5 July 1989.

Meteer, M.W. *The SPOKESMAN Natural Language Generation System* (Report No. 7090). Cambridge, MA: BBN Systems and Technologies Corporation, DRAFT of July 1989.

Orlansky, J. and Thorpe, J. *SIMNET -- Engagement Training System for Tactical Warfare*. *Journal of Defense Research*, 1989, in press.

Pope, A.R., Langevin, T., Lovero, L., and Tosswill, A.R. *The SIMNET Management Command, and Control System* (Report No. 6473, Revised). Cambridge, MA: BBN Systems and Technologies Corporation, July 1988.

*Semi-Automated Forces: Version 3.x -- Design Guidance* (Technical Report ITR-1001-6/89c). Newbury Park, CA: Illusion Engineering Incorporated, COORDINATING DRAFT of 19 July 1989.

*SIMNET Command Modules: Simulation for Joint and Combined Arms Operations at Echelons above Battalion -- Data Handbook* (Technical Report PTR-4106-07-1200-88-12). Chapters 1-4. Woodland Hills, CA: Perceptronics, DRAFT of 22 December 1988.

Thorpe, J.A. *The New Technology of Large Scale Simulator Networking: Implications for Mastering the Art of Warfighting*. In, *Proceedings of the Ninth Interservice/Industry Training Systems Conference*. Arlington, VA: American Defense Preparedness Association, December 1987.

Turner, N., Sykes, P., Smith, G., Krishnamurti, R. *SIMNET Semi-Automated Forces Version 3.0: Radio Net Simulation* (Report No. 7079). Cambridge, MA: BBN Systems and Technologies Corporation, 8 June 1989.

**APPENDIX C**  
**PANEL MEMBERS' COMMENTS**

## **COMMENTS ON SIMNET/SAFOR REVIEW**

### **AUGUST 10-11, 1989**

**Rodney A. Brooks**  
**MIT Artificial Intelligence Lab**  
**Cambridge, MA**

**August 17, 1989**

#### **1. The Project**

The overall impression of the SIMNET project, and the Semi-Automated Forces (SAF) project in particular, was very good. The BBN team has been working very quickly to produce real systems and has made great progress in a very short time frame, apparently under the pressure of changing goals.

The team as its stands is very innovative and creative. Without additional manpower it does not seem appropriate to add new goals to their already busy agenda. Also it does not seem appropriate to task the current team with conversion to Ada---such a task would be wasteful of their talents and would slow the whole innovative process down significantly.

#### **2. Hardware**

A particular question raised concerned short term hardware acquisitions to scale up the size of the SAF that could be operated on SIMNET.

The current hardware for SAF is the BBN Butterfly parallel processor. One of its cited strengths is the ability to add more processor nodes without significantly slowing down the shared memory access time. In comparing numbers, however, it seems that a Butterfly with sixteen 68020 processors could rather easily be beaten by a MIPS box or a SUN-4 uniprocessor, without any overhead for shared memory between processors. A 32-node Butterfly might also be bested by such a processor at a significantly lower cost.

However, there would be a significant software penalty in making a change, and it would impact very badly on the short-term goals of the project. It seems prudent to stick with the Butterfly for now, but to make efforts to ensure that coding standards are such that



the SAF code will be completely portable eventually, so that hardware platforms can be seamlessly replaced to take advantage of the increasing processing power available in modern workstation processors.

### 3. Objectives

There seemed to be some confusion over the goals of scaling up the SAF size, no doubt reflecting different constituencies within the customer.

One argument for scaling up SAF is so that individual crews in tank simulators can experience some of the large scale aspects of battle that are not generated by, say, 300 tank simulators. Another argument calls for training commanders at the regiment, division and corps level by giving them large-scale exercises.

In the first case, it is easy to see problems ahead in making the SAF tanks indistinguishable from manned simulators. In a *fight to win* situation any such distinguishability will be seized upon by the human participants to gain advantage. There are some short-term improvements possible in the realsim of the SAF, mostly by adopting results learned from the DARPA ALV program (e.g., the Hughes AI Lab work on cross-country terrain following). However, there are harder issues concerning learning, etc., which seem hard to address in the long term.

In the second case, it is not completely clear why each vehicle needs to be simulated as an individual entity. Large performance increases may be gained by having aggregations of vehicles which are only there when you look at them, and otherwise are hidden in the larger-scale units, which are simpler to simulate.

It is worth noting that for significantly less than \$20B it would be possible to replicate the current hardware to provide enough simulators that the whole U.S. Army could be involved in a battle simulation simultaneously.

### 4. Scaling Up

In terms of scaling up the current level technology SAFs to simply have more of them, it seems that in general the scaling will work in a linear or sub-linear fashion.

Statistics from instrumented simulations on the Butterfly were presented. Seventy percent of all computation was well accounted for and it seems sure that all of that computation will scale up in a fashion no worse than linear in the size of the SAF.

Unfortunately, thirty percent of the computation was unaccounted for. It is unclear where this computation goes, and therefore unclear whether it scales well. It may be that it is being consumed in some sort of message conflict resolution at the network level, in which case it may not scale well. It is important to monitor this component of the computation carefully in initial scaling experiments to see what happens to it.

## **5. Adaptability**

Currently, all aspects of the system are rather hidden from users of the system, including commander planning, doctrine, equipment descriptions and the terrain data base. It would be beneficial if end users could have mechanisms to modify all these components without having to go out to government contracts to get things modified. This is a long-term goal.

However, in the short term it seems that the SAF commander may need more flexibility in his options for creating plans for his forces. Currently he is able to mix and match a set of predefined plans (in the TARL/E language) and feed them down to his SAFs. Greater realism would ensue if he had a richer interface to these plans, and could do the sorts of operations that now must be done by a knowledge engineering programmer in order to create or change a TARL/E plan.

## **6. Learning**

SIMNET has demonstrated how manned forces adapt and learn as they try out weapon systems and doctrine. They modify their behavior. The red forces also modify their behavior and there is a continual interplay between the competences of the two forces as they gain experience. For realism of the SAFs some of these aspects should also be simulated.

To some extent parameter adjustments in the SAF over time can improve their performances. However, they will be dumbfounded by innovative tactics developed as experience grows among the human participants. This could lead to the human participants discerning SAF from other manned simulators. Rectifying this situation is not a practical short-term goal, but rather an area that DARPA could fund as longer-term research. Appropriate RFPs would probably lead to strong responses from a number of laboratories with interests in these areas.

## **COMMENTS ON SIMNET/SAFOR REVIEW**

### **AUGUST 10-11, 1989**

**Bruce G. Buchanan**  
**University of Pittsburgh**  
**Pittsburgh, Pennsylvania**

#### **1. Overall Impression**

Excellent work at all levels from problem definition and management to implementation. The actual coding is an impressive tribute to what a small, dedicated team can do with an exciting project.

#### **2. Hardware**

Because the technology changes rapidly it is easy to suggest alternative hardware configurations that offer improvements over yesterday's choices. However, the cost of changing over to new machines in the next year are sufficiently high that the current rapid rate of development would be slowed unacceptably.

#### **3. Objectives**

There are many implicit objectives driving the development of SIMNET and SAFOR. Both training of personnel and evaluation of new weapon systems are worthwhile goals, but they imply different priorities. Even within either of these two major goals, there are many alternatives for directing the project. For example, training division commanders implies considerably more effort on artificial intelligence in the automated forces than does training platoon commanders. The project derives some of its vigor from lack of precise objectives, for this lets the staff exploit opportunities as they arise and exercise considerable ingenuity in doing so. On the other hand, transfer to the Army implies that the objectives of SIMNET are very precise, so that the reimplementation team can make the proper trade-offs, for example, in questions of human engineering (precisely who are the intended users?) and efficiency (which parts of the code will be exercised most?).

#### **4. Scaling**

Answering the question about objectives will help answer the question of which ways to scale up the system. Adding more units implies different effort from adding more battlefield functions, such as intelligence. The proposed method for scaling up is to add more computers and more memory. This will probably work, since the potential problem of exponential growth appears to be avoidable. System overhead, and other computing cycles not well accounted for (about 30% of the total) need to be examined, however, to be certain that they are not growing exponentially.

Another method for scaling up, which needs to be examined more carefully, is omitting unnecessary detail. The SIMNET philosophy is to include all details in order to be certain that fidelity is maintained. Of course, even SIMNET omits some details, such as the interactions among individual crew members, battlefield smoke, civilian behavior, etc. So it is recommended that this issue be reconsidered for details of individual vehicles when operating 2-3 levels (or some number of levels) above individual vehicles. Possibly, too, the psychological fact that we attend to about seven plus/minus two items (whether vehicles or large battle units) may be exploitable. By aggregating and expanding (de-aggregating), the current SIMNET computers may be able to handle two orders of magnitude scale-up with acceptable fidelity. The issue is not as clear as the philosophical axiom of including everything, but some reconsideration is recommended before millions of dollars are spent on scaling up by adding hardware and redesigning software to cope with 300,000 items.

#### **5. Modifiability**

Once the program is out of the hands of the BBN design and development team, it will be necessary to provide better tools for modifying the program and data structures. It must be clear, also, who is capable and who will be allowed to make changes. The system can only live on its own, however, if Army personnel (at some level) can reconfigure units, add or modify equipment and doctrine, and define new terrain.

#### **6. Adaptive Behavior**

Proposing automatic learning in any units opens the SIMNET team to a large research area. In the long term this may be valuable, for example, for SAFOR commanders to improve their own tactics. There are too many other, more pressing problems for the short term, however. If individual SAFOR vehicles and units adapt to new situations more readily because they have more intelligence and more autonomy, there

will be less need for them to pause and request instructions. This is desirable to work on in the short term.

## **7. Validation**

What can be measured to convince developers, funders, users and skeptics that SIMNET makes a positive difference? Again, clarification of objectives will help. It clearly can save money over full-force exercises requiring large airlifts. But is the quality of training high enough to accept the loss of fidelity? Probably so, but how do we know ?

## **8. Audit Trail and Replay**

Much more can be done with replay capabilities. Part of the design philosophy is that personnel will learn best by running through a high-fidelity simulation without stopping. This is imposed on SIMNET by the fact that there are too many players for back-up-and-replay to be efficient. When there is a single commander with all SAFOR units, however, the situation is very different. Learning does increase through analyzing mistakes and working through them. Pro football teams have used films and drills for decades, for example.

Further study of exploiting SIMNET's audit trail is recommended.

## **COMMENTS ON SIMNET/SAFOR REVIEW**

**AUGUST 10-11, 1989**

**Douglas B. Lenat  
Artificial Intelligence Project  
Microelectronics and Computer Technology Corporation  
Austin, Texas**

My overall reaction was surprisingly positive. "Surprising" because I believed I was cognizant of the good work being done in relevant areas of AI, simulation, and DARPA-related research; yet here was an unfamiliar project right in the intersection of all three areas. And "positive" in the sense that the group has achieved a great deal, in a small period of time and given very limited hardware and budgetary resources.

We were asked for our comments on several issues, and a "consensus opinion" was delivered verbally at the end of the day. Below is my personal opinion; I have marked with an asterisk (\*) the points which I may be adding to the consensus opinion. Unstarred points are ones in which I believe the rest of the scientific advisory group already has discussed the issue and agrees with the point as I present it.

### **Issue: What's good about what they've accomplished?**

The successful blending of several forefront technologies is rarely doable, and never painless. In this case, the team has produced a seamless integration of local area networking, long haul networking, physical simulators and displays, and so on, while maintaining a good level of training and motivating of the test subjects, motivating of the funders, producing milspec documentation, and giving briefings such as this meeting. Throughout the meeting, I was consistently impressed with the people who spoke (these were mostly the BBN researchers). Their level of intellect, competence at their task, motivation, and achievement was quite astounding.

### **Issue: What's bad, or a "warning sign", in the project at present?**

(i) One obvious weak point is the documentation. Although there is a vast stack of it (thousands of pages), and it meets milspecs, it is quite jargon-laden and almost impenetrable to anyone not already familiar with the project. If I had been sent this

documentation before agreeing to come to the meeting, I would have declined the offer. I am therefore glad I didn't get the docs until just before stepping on the airplane. I shall have more to say about improving this situation, below. (ii) A second "danger sign" is the bitterness that was evident as an undercurrent in some of the talks and remarks we heard. By "bitterness" I mean a feeling that the group had made a heroic effort, achieved a wild success, and yet was being continually pressured and harried by their bosses and their funders to do much more, and more quickly. Their edginess over this is a warning sign of impending burnout. Given their experience and abilities and track record, I hope that steps are taken to relieve this pressure somehow. (iii) A third warning sign was the military's assumption that "bigger is better" (if SIMNET works on 300 units, let's try 3000 or 30,000) almost without being willing to question whether such scaling up makes sense. All three of these potential problems are discussed further, below.

**\* Issue: How would you suggest ameliorating the documentation problems?**

The documentation problem could of course be solved in the usual way (hiring a documenter), but I recommend a more knowledge-based, on-line approach. Specifically, I recommend building a KB (knowledge base) that knows about the system, has libraries of cases which it can run, etc. This program can be used in three separate ways: (a) Via a text generation program, to produce a document of the system. Depending on the user model -- military spec, novice news reporter who is to try using the simulator, AI expert unfamiliar with the project, etc. -- the actual document generated would be different. (E.g., the AI expert version would explain the military acronyms; the milspec version would explain the AI terms.) (b) Via an ICAI program, to provide on-line training for a new user (or, again employing user models, provide on-line "training" for a new project team member, funder, scientific advisory board member, etc.) (c) Have a mode in which the large case library is quickly "run through," and the results checked with what the documentation predicts they should be. This is a way of automatically detecting bugs accidentally introduced into the system, and of detecting undocumented changes and updates to the system (which would make the documentation incorrect.)

**\* Issue: How would you suggest ameliorating the morale problem?**

This is more subtle, but I would reward the BBN team members in various ways: (i) allowing and encouraging them to attend relevant conferences (such as AAAI or IJCAI, and the annual Machine Learning conference); (ii) allowing and encouraging them to write

up some of their work for publication at conferences, in journals, and, specifically, in the AI Magazine; (iii) having more of these scientific advisory panel meetings, which allow them to trade ideas and receive positive feedback from their colleagues; (iv) providing more resources and relaxed, rather than accelerated, time pressure, Ada pressure, etc. Although I feel strongly about this, I should reiterate that this is still only at the "danger sign" stage, not already a factor hampering the project. The individual researchers are still putting in long hours, are enthusiastic about the goals of their project, and so on.

**\* Issue: What is "missing" from the project?**

There are two factors which might be missing -- and thereby distorting the results -- at the level of the individual soldier sitting in a simulated tank. These two factors are (a) terror, or at least very serious self-interest that that soldier should feel during the exercise, and (b) distractions and work involved in communicating with the various other crew members in that same tank. Factor (a) could be dealt with by having, say, real money at stake over the outcome, or by having a team spirit develop as with athletic competitions. We have heard that, unofficially, of course, both of these are already happening. Factor (b) is completely lacking, though, at present, and it would be relatively easy to fix. That is, the program would now and then generate messages and tasks "from his crew" which the tank commander had to respond to, thereby bleeding away some of his attention and time. Talking with tank crews involved in combat should provide the necessary heuristics for the types of messages, the frequency, how this changes under fire, how it changes as the tank becomes damaged, and so on. This has already been a highly recognized factor in the verisimilitude of command simulation at a higher level; that is, the company commander is not getting properly trained if he gets to sit and watch the progress of the battle, move units around, etc., and needs only to talk to his superior officer. It is recognized to be much more realistic to have much of his time taken up with chatter with his subordinate commanders. I am just suggesting that the same point applies at the level of the individual tank, not just at higher levels.

**Issue: Is the current choice of hardware, software, networking, etc., adequate, both at present and in the case of scaling up?**

Our answer here is a reluctant Yes. The choices were reasonable at the time they were made (1983), but today we would make different ones (e.g., going with fast uniprocessors, such as the DEC-3100, rather than the slow and idiosyncratic Butterfly machines.) However, the vast cost to change now (in terms of lost dollars, months of



time, momentum, familiarity,...) is not worth it. When and if the system is re-engineered and rebuilt from the ground up, one day, then it would be appropriate to re-visit this question and probably take a different path. The choice of the C language, e.g., represents a compromise between efficiency (needed for realtime simulation) and ease of development (easier than in Ada, harder than in Lisp), and again we reluctantly endorse the group's continued use of it. If there is increased pressure from the military for them to convert SIMNET to Ada, that should be resisted; in the end, perhaps the SIMNET nodes can be conceptually packaged and sold as black boxes, with very specific interfaces which can then be hooked together by a little bit of Ada code. If there is pressure from the AI research community (such as myself) to convert SIMNET to Lisp, perhaps that, too, should be resisted, at least until it can be shown that the real-time behavior will not degrade.

**Issue: Will SIMNET and SAFOR scale up to larger (3000) and larger (30,000) forces ?**

Most of the algorithms do indeed scale up linearly. There was some confusion about 34 percent that might not; we are not claiming anything about this 34 percent -- we aren't saying it's worse than linear -- we simply weren't told (and the researchers haven't yet classified) what that 34 percent of the time was going to. This needs to be watched, as the scaling proceeds. However, the fact that humans are capable of doing this activity in real life is an "existence proof" that linear solutions exist to, e.g., the communication problem, the attention problem, and so on.

**Issue: Should this be scaled up, to 3000 or 30,000 units?**

This is a different issue, and one we were not explicitly asked to consider. However, there seem to be two possible purposes of the entire system, and they each -- to my mind -- suggest a No answer to this question. (i) The purpose is to train better tank commanders, and perhaps company commanders. In this case, there is little to be gained by scaling up at all. Fred (who's in tank 42) doesn't really care what is happening at the division level, let alone some other division. Look at it this way. There has to be some level below which it's not cost effective to simulate (e.g., the irrelevant switches in the manned simulators are just painted on; the head and arm motions of the individuals in the SAFOR simulated tanks are not worth simulating; etc.) And there has to be some level above which it's not cost effective to simulate (e.g., the politics and economics that are happening while the battle is going on.) It is possible to pick an incorrect "lower level" -- indeed, this was my point, above, about needing to simulate each individual in the tank,

even though only the tank as a whole is visible to an external advisor. And it is possible to pick an incorrect "upper level" as well. (ii) The purpose is to train better brigade, division, regiment, etc., commanders. Here, the lure is that by having actual soldiers in the simulated tanks, there will be useful rich detail added to the simulation "from below," for these individuals. But, following the argument we just made, it's hard to see why there needs to be anything more than a simulation running two or three levels "below" the individual being trained. If they want to go out on the field and look it over, the simulator ought to be able to provide a realistic enough view of what might be happening. So, whether you choose purpose (i) or (ii), you don't need a massively scaled up simulation exercise. Only if you want the same system to simultaneously do both tasks do you need the scaling up. It is important to realize that I am not saying "don't invest more resources into this project". It is a marvelous project, as I've repeatedly stated, and certainly deserves whatever extra resources can be found for it. Rather, it is a question of how best to use those resources, and whether just blindly scaling up is the right way to go.

**\* Issue: Should the project expand in other ways?**

A direction I think might be very productive would be to make the simulator more predictive, more proactive rather than just reactive. In other words, try to envision what the tank commander is likely to do next, and what the company commander is likely to do next, etc., to make the system response even more seamless and instantaneous, to make the simulated tanks' behavior (both friendly and hostile) more realistic (rather than having them just report to the human company commander that some unanticipated situation has arisen, such as a bridge being blocked or destroyed, or... well, if I could list them here they wouldn't be unanticipated, would they?) Very low levels of prediction are already being taken advantage of (the places this tank is likely to go in the next instant). Higher levels would require two additional capabilities: (i) Scenario generation -- spinning plausible chains of cause and effect, and planning for both their display to the humans in the loop, and for appropriate reactions of simulated vehicles in the scenario. Even if that appropriate reaction must be considered and decided manually, the idea is that it can be done before the actual SIMNET battle is fought, being driven by machine-generated scenarios rather than waiting until the situation arises in realtime SIMNET combat. (ii) Common sense -- including both having a vast real world knowledge base of facts, heuristics, representations, etc., about objects and actions, plus having a large repertoire of common sense reasoning methods. This gives the simulated vehicles a chance of coping with unexpected situations. For instance, if a commander decides to try crossing a stream by

driving over the tops of half-sunk recently-destroyed tanks...; or if a pilot tries to fly under a bridge...; or if a pilot in a badly damaged plane tries to crash into a tank or -- even more interestingly -- a fuel depot; or... well, you get the idea. Both (i) and (ii) are immense tasks in their own right; the best way to add these capabilities might be via collaboration. One particular pointer relevant to Scenario Generation is the work on the Strads program at ESL (contact: Al Clarkson, 408-738-2888). One particular pointer relevant to Common Sense is the immense KB for that purpose we are building at MCC, namely the CYC program.

**Parting shot:** Let me conclude by remarking that this is only the second project I've seen in almost two decades of such panel meetings, advising, and consulting, where my reaction has been "I want to get more actively involved in this!" Three possible roles I see for myself are (a) member of a scientific advisory board for the project, which meets periodically to review progress and make recommendations, (b) consultant with the BBN researchers, giving more direct technical feedback and suggestions, and/or (c) collaborator, by pursuing the proposal (above) to have SAFOR cope with novelty by drawing directly on the common sense in CYC.

## **COMMENTS ON SIMNET/SAFOR REVIEW**

### **AUGUST 10-11, 1989**

**David M. McKeown, Jr.**  
**Digital Mapping Laboratory**  
**School of Computer Science**  
**Carnegie Mellon University**  
**Pittsburgh, Pennsylvania 15213**

**August 15, 1989**

The working group was convened by Dexter Fletcher of IDA on August 10, 1989 at the Rosslyn SIMNET Facility. The group consisted of Rod Brooks (MIT), Doug Lenat (MCC), Bruce Buchanan (PITT), and myself. Lt. Col Jim Shiflet (U.S. Army) and Col. Jack Thorpe (USAF) gave a brief introduction to the SIMNET program and described the follow-on effort to expand the scope of SIMNET along several dimensions. Of particular interest to this group was the design and development of semi-automated forces (SAFOR) that could be used to simulate friendly or opposing forces in order to provide the ability to simulate larger scale engagements. Given the cost of manned simulators it was felt that in order to accommodate more realistic battle scenarios, including aircraft and naval components the development of simulated forces was the only way to provide for realistic engagements at the battalion, regiment, or corps level. Our charter was to listen to and evaluate the proposal/plan to develop SAFOR along the following four dimensions:

1. Sizing space
2. Response time requirements
3. Flexibility / extensibility
4. Short term / long term issues

Since we have, as a group, already summarized our findings to Dexter Fletcher and presented them to the SIMNET 'Committee of 5' I will restrict my comments to those that might refine the general recommendations and observations somewhat outside of the scope of our general charter.

## **Terrain Issues**

At several points in the discussion statements described one of the primary goals of SIMNET to allow soldiers to train in an environment 'modeled on real world terrain' and 'support to fight anywhere'. The natural implication is that as SIMNET expands beyond the current hand-generated gaming areas the requirements to have a highly detailed spatial data bases will increase. Further, future directions such as radar simulation, modeling radio communications, etc., towards an ideal Defense Simulation Internet will place increasing importance on the generation and maintenance of spatial data. It is likely that the SIMNET program will have to directly support such efforts, or be a strong advocate within the Defense Mapping Agency and the U.S. Army to support the production of specialized data on which the simulations are based.

The terrain level-of-detail allowed by the CIG component is far coarser than the level-of-detail required to support navigation and terrain reasoning. While they need not (cannot) be the same, they should be derived from the same underlying data base so as to maintain consistency and coherency in the simulation.

This will become especially true as the SAFOR development continues. Many problems will arise if the SAFOR can plan navigation and evasive maneuvers on a terrain model that either can't be portrayed or can't be seen by the manned forces. A second problem is that the current level of detail may smooth out many significant terrain features that are key to manned training. For example, gullies, ravines, and other natural terrain features may be too detailed for the CIG component and not be easily modeled.

## **Planning Issues**

Plans that can be modified during an exercise appear to the user as a set of primitive building blocks that can be linked together to suit the particular situation. However, it was unclear what types and levels of exceptions could be supported using TARL. Does this lead to stereotypical behavior by SAFOR, and if so, how does this impact the desire to make SAFOR forces indistinguishable from manned units.

Along a similar line, the current route planning techniques are clearly inadequate. However, even if the current state-of-the-art ALV routing algorithms were employed it is not clear whether these capture the types of constraints used in terrain masking during cross-country movement. Some effort ought to be placed in understanding the tactics of cross country movement, as opposed to simple point-to-point navigation with obstacle

avoidance. For example, there is a natural tension between maintaining formations and local planning.

There seems to be an asymmetry between the level of replanning performed by manned units and the level described for SAFOR. How important is dynamic plan adjustment?

### **System Integration and Evaluation**

I have the impression that more isolated testing of the SAFOR forces is needed in order to insure that their behavior can be incrementally evaluated and improved. I do not have a good impression that the BBN team has a plan for test and evaluation before unleashing SAFOR on users. In my opinion some significant effort will be required to get the SAFOR subsystem to a useful level of play. Evaluation ought to determine whether humans can distinguish between manned and SAFOR vehicles.

What is the test plan for SAFOR? What constitutes an acceptable level of performance? What is an appropriate ratio of manned to unmanned units?

As was discussed in the summary meeting, the timings presented do not adequately allow us to make a judgement as to whether the current architecture can support one or two orders of magnitude more simulated vehicles. As a part of the performance analysis portion of the follow-on contract, some effort should be expended on a much more detailed measurement of the system load and overheads (largely unreported on) and whether the Butterfly architecture can support extensions without saturation of the memory interconnect network. Again, there seems to be a lack of understanding of the dynamics of the simulation.

In addition to the previous point, that calls for better measurements of the current state of the simulation, there is a significant possibility that increased reasoning about the terrain and in executing plan exceptions could greatly change the timing mix of the tasks that must be performed by the SAFOR. The current path planning is the most simplistic technique that still encompasses search. However, the global optimization of A\* is not likely to be representative of the computational load required for adaptive search including terrain and mission constraints.

## General Issues

There appears to be an obvious tension within SIMNET in deciding what role future evolution of the program should take. The fundamental question is who/what is SIMNET trying to affect/train/impact? There does not appear to be a clear consensus on this issue. One view might be that SIMNET has shown effectiveness as a training aid at the battalion and company level and should therefore be extended to the regiment and divisional support. Another view is that there are many holes in the current level of realism at the battalion and company level and these should be addressed before trying to scale up to larger scenarios.

The stated goals of getting SAFOR to a point of sophistication where an entire regiment or battalion could be simulated by one person is clearly driven by the desire to perform larger scale simulations as efficiently as possible. It is unclear whether the state-of-the-art in terrain reasoning, utilization and operationalization of tactics and doctrine, and in real-time analysis of multi-purpose agents will support such a goal. Driving the SIMNET project in this direction prematurely will probably result in a failure. It is not clear to me that even in the long term (5-10 years) full simulations as envisioned in the Defense Simulation Internet would be practical at a level of realism that would be acceptable as fulfilling a training goal. Backing off from the concept of a highly independent SAFOR acting with intelligence and cunning can be achieved by keeping more men in the loop. While this might appear less cost effective, it probably keeps SIMNET on a more traditional development path, rather than straying into basic research.

**APPENDIX D**  
**SAFOR BRIEFING MATERIALS**



**Semi-Automated Forces  
Concepts and Approach**

**Stephen Downes-Martin  
BBN Systems and Technologies Corp  
10 Moulton Street  
Cambridge, MA 02138**

- **Problem Domain**
- **Problem Statement**
- **Technical Requirements**
- **Scope the Problem**
- **Expand the Goals**
- **Underlying Concepts**



## **Problem Domain**

- **Tactical Combined Arms Combat**
  - **An adversarial high risk high intensity real time activity in an uncertain and lethal environment which integrates the maximum use of violence with the maximum use of intellect.**
  
- **Agents (many variants of each)**

<ul style="list-style-type: none"><li>• <b>Vehicles</b></li><li>• <b>Weapons (vehicle mounted)</b></li><li>• <b>Units</b></li></ul>	<b>In a Soviet Regiment</b> <b>600, 50 types</b> <b>10 types</b> <b>12 functional types</b>
---	--
  
- **Activities**
  - **Planning, execution, monitoring, diagnosis, prediction.**
  - **Battlefield Functional Areas (BFA)**
    - **Maneuver, Fire Support, Air Defense, IEW, C3I, MCM, CAS and BAI, CSS.**
  - **Cognitive and physical.**
  - **Complex and interactive.**
  
- **Complex domain exhibiting breadth and depth**
  - **Each command level introduces new concepts, agents, and tasks: the whole is greater than the sum of its parts.**
  - **Non linear growth in complexity with command level.**



## **Problem Statement**

- **Provide a Command Post Interface to SIMNET so that a TOC commander and staff can command and control large forces (flank, supporting, enemy), without the requirement of manned simulators, which interact on the SIMNET battlefield. This will be achieved by the use of software driven semi-automated forces (SAF).**
  
- **Use SAF within the SIMNET arena to support**
  - **Joint and combined arms training.**
  - **Combat developments.**
  - **Large scale high resolution combat simulation.**
  - **Integration of command, team, and crew training.**



## **Design Guidance**

- **SAF is a manned simulation. Humans are in command. SAF is manned by commander and staff of the highest echelon represented. Humans fight to win.**
- **SAF machine intelligence executes human command guidance in accordance with doctrine and with sufficient operational realism that battlefield tactics are not affected. A weak form of the Turing Test.**
- **Critical tactical decisions are reserved for the human commander. SAF system provides advance warning.**
- **Human commander and SAF interact via formatted military messages (OPORDs, FRAGOs, Requests, Reports). They carry out their warfighting tasks in a manner as close as possible the real world.**
- **Human commander can relocate focus of awareness and control to any software subordinate.**
- **The SAF must work -- goal driven R&D**
  - **Demos are hands on warfighting exercises by soldiers.**
  - **Demos are a subset of broad but focussed R&D.**
  - **Deliverables are a robust subset of demo functionality.**

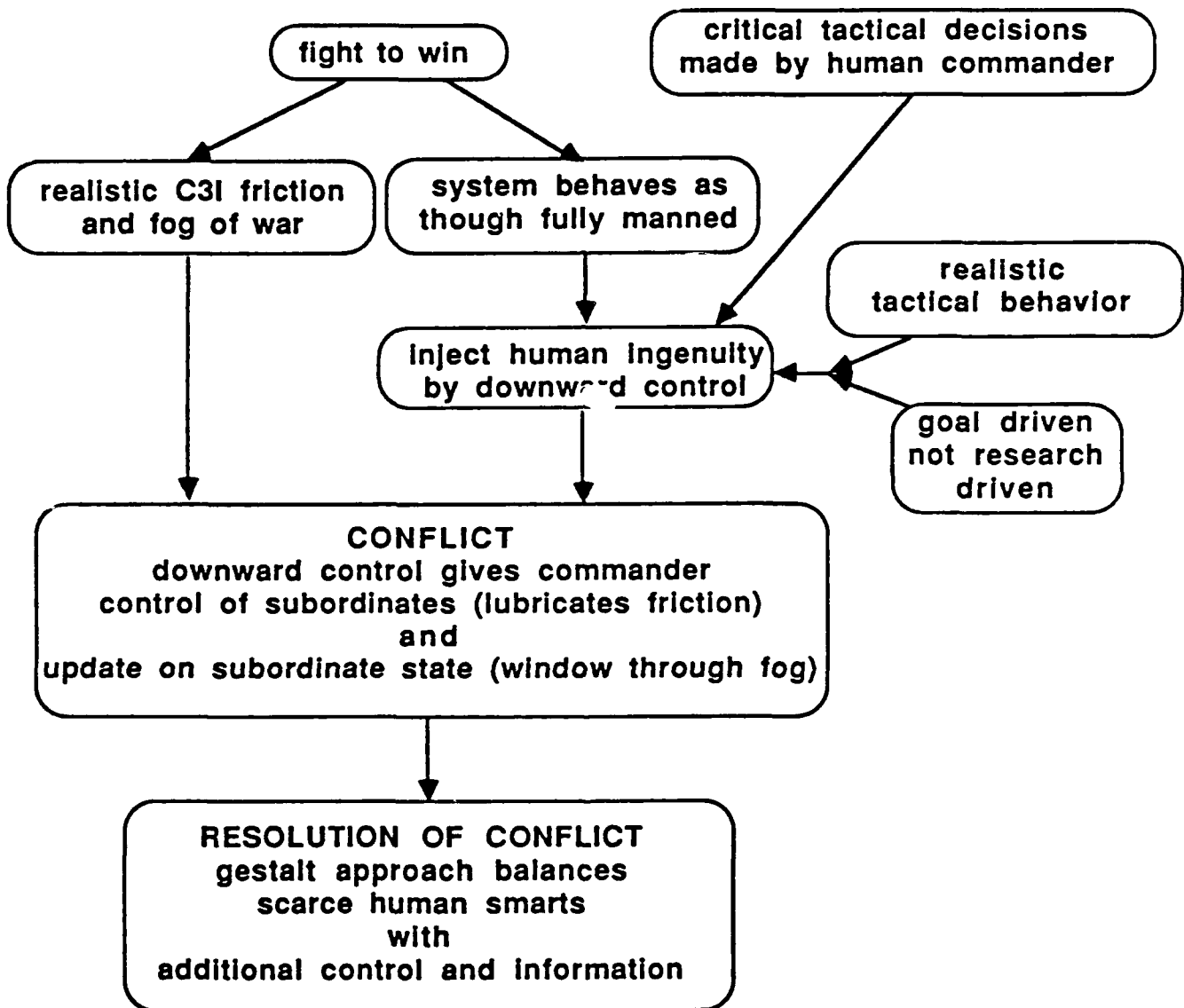


## Technical Requirements

- **SAF Interacts with SIMNET. Humans in manned simulators can eyeball the SAF BOS**
  - **Maintain physical integrity of SAF BOS.**
  - **SAF BOS operate at similar response rate to manned simulators.**
  - **SAF BOS operate at similar levels of realism to manned simulators.**
  - **Must simulate BOS crew performance as well as BOS equipment performance.**
  - **SAF BOS and manned simulators share some computational requirements on external performance. Minimum computational requirement exists driven by realistic appearance requirement.**
- **SAF Interacts with human TOC. Humans In TOC can command and control subordinate SAF units.**
  - **Must simulate communications flow between human TOC and subordinate SAF units.**
  - **Must provide decision support software for TOC.**
- **SAF BOS are software driven**
  - **Must simulate warfighting tasks of subordinate SAF units.**



## Conflicts Between Requirements



## **Problem Scoping**

- **Bound the problem breadth**
  - **Identify critical tasks and activities.**
- **Bound the problem depth**
  - **Identify what is good enough for tactical reality.**
  - **Use domain knowledge, two thousand years of documented expertise.**
- **Avoid research black holes -- performance directed**
  - **Human commander carries out hard cognitive tasks.**
  - **Generate fully-manned appearance by gestalt approach**
    - **Human can insert himself into any decision node.**
    - **Human in supervisory control of software.**
  - **Avoid re-inventing the wheel**
    - **Judicious integration of many techniques.**



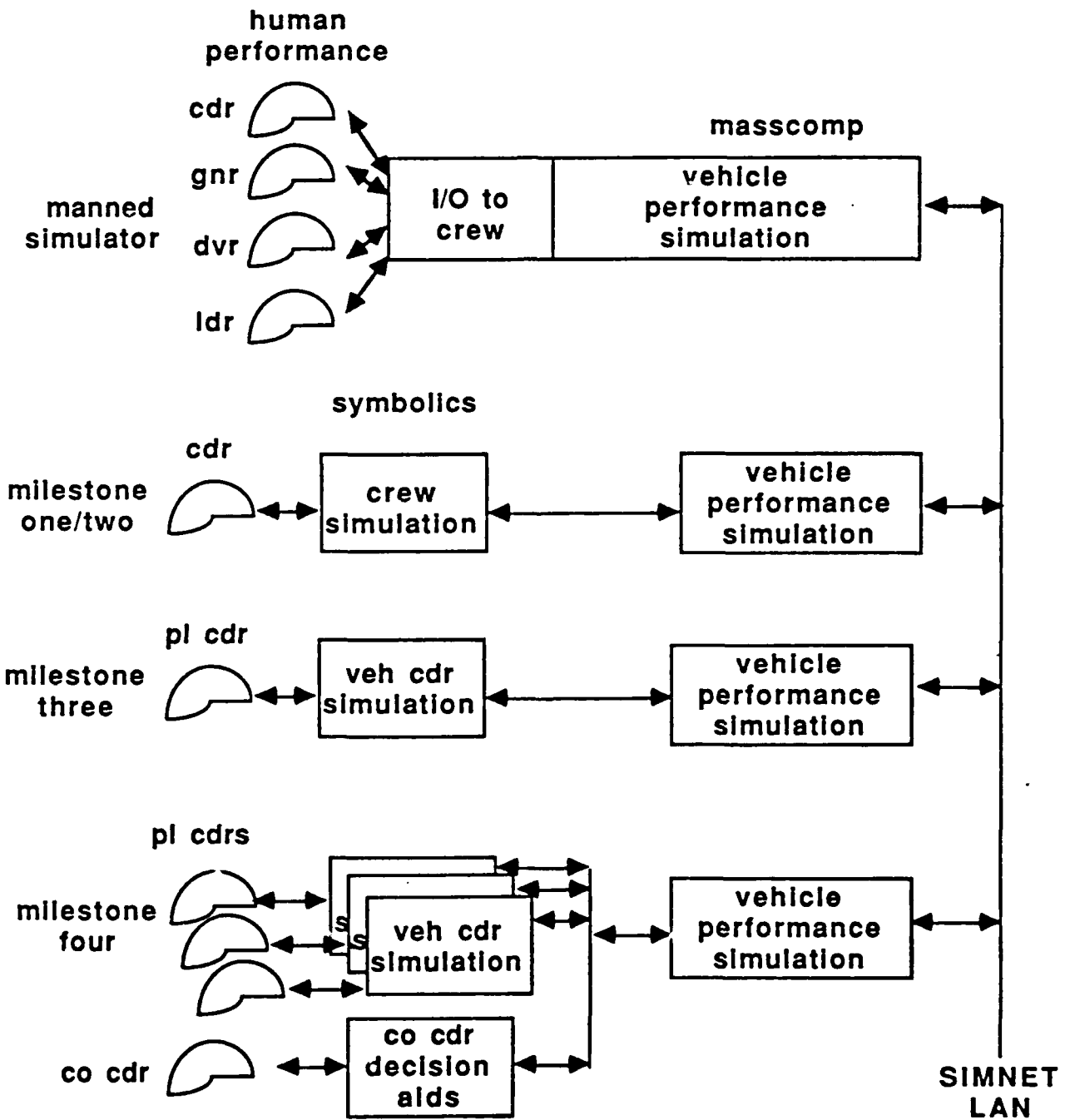
## **Original Goals**

- **Spring 1986 – Original proposal accepted by DARPA**
  - **OPFOR Armor only.**
  - **Fire and Maneuver only.**
  - **Platoon level workstations control SAF platoon vehicles.**
  - **Company workstation communicates with platoon workstations.**
  - **Concentration on autonomous and cooperative behavior at the platoon level to establish techniques for future expansion .**
- **Milestones**
  - **Simulation of tele-operated vehicle.**
  - **Autonomous vehicle.**
  - **Cooperative behavior between vehicles.**
  - **Platoon commander's workstation.**
  - **Cooperative behavior between platoons.**
- **Five full time equivalents, thirty months duration.**





# Original Approach



## **Goals Expanded as Project Develops**

- Mar 1986: Original proposal accepted, delivery Fall 1988.
- Nov 1986: Future expandability becomes a goal
  - Focus efforts away from intelligent behavior and onto SMI.
  - Include automatic explanation.
  - Avoid risky AI research.
  - Expand from platoon to regimental workstation.
  - Include artillery.
- Two order increase in vehicle numbers. Begin parallel effort into Butterfly implementation. Butterfly chosen as most cost effective in 1986 with incremental expansion capability.
- Jan 1987: Goals expanded
  - Include helicopter and fixed wing aircraft.
  - Field system by Aug 1987.
- Mar 1987: Goals expanded
  - Workstation requirement reduced from regimental to battalion.
  - Include logistics.
- May 1987 Demo
  - Version 1.0 at Armor Conference Ft Knox.  
Masscomp based, ground, red, company workstations.
- Dec 1987: Goals expanded
  - Include US units and tactics.
- Mar 1988 Demo
  - Version 2.0 at FAADS Test Ft Knox.  
+ Butterfly based, air, blue.
- Mar 1989 Demo
  - Version 3.0 distributed SAF PoP demo.  
+ Integrate ground and air, battalion workstations.

**Advanced Simulation Division**



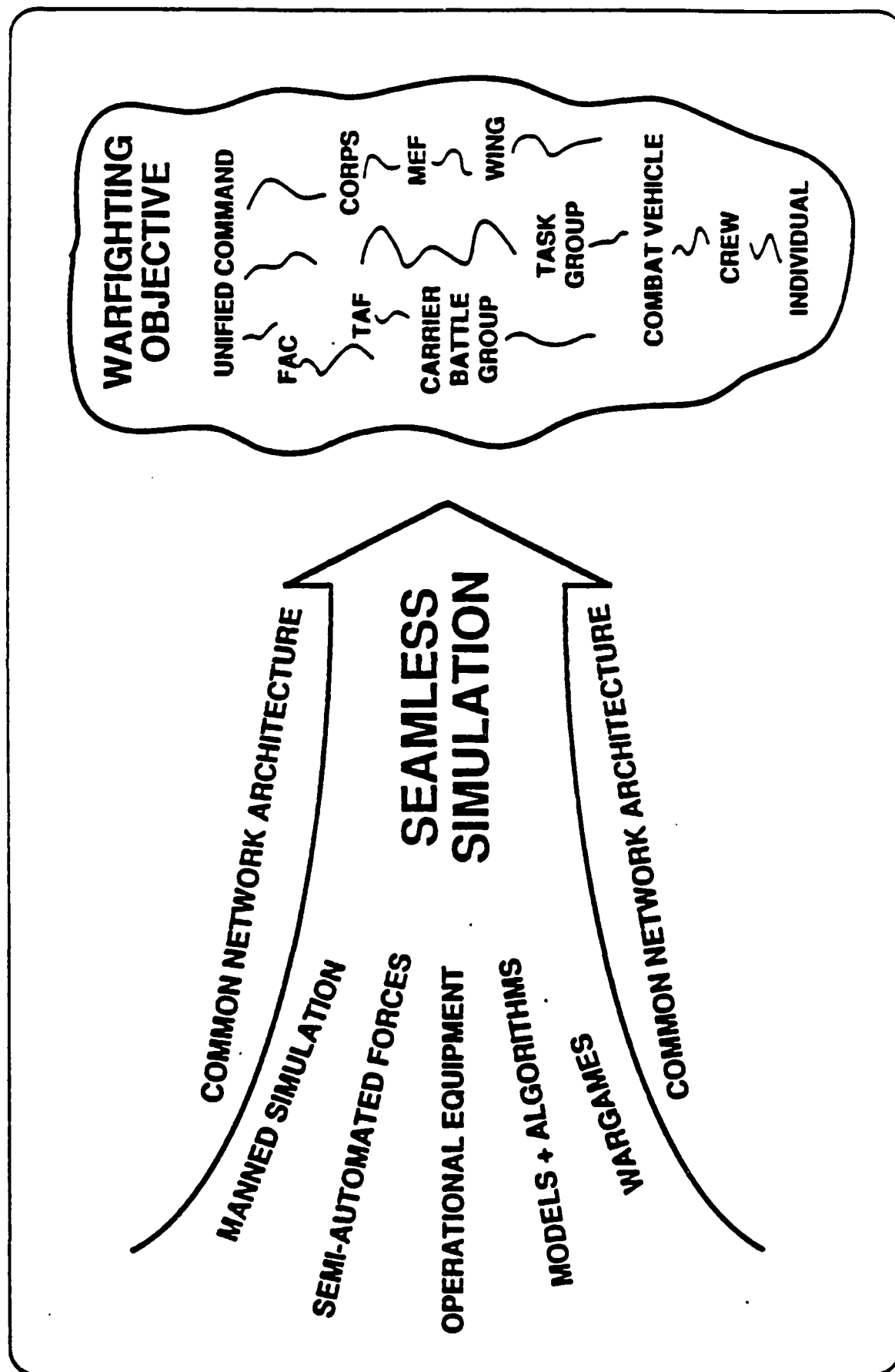
## **Vertical Scaling**

### **The Advanced Battle Simulation (ABS)**

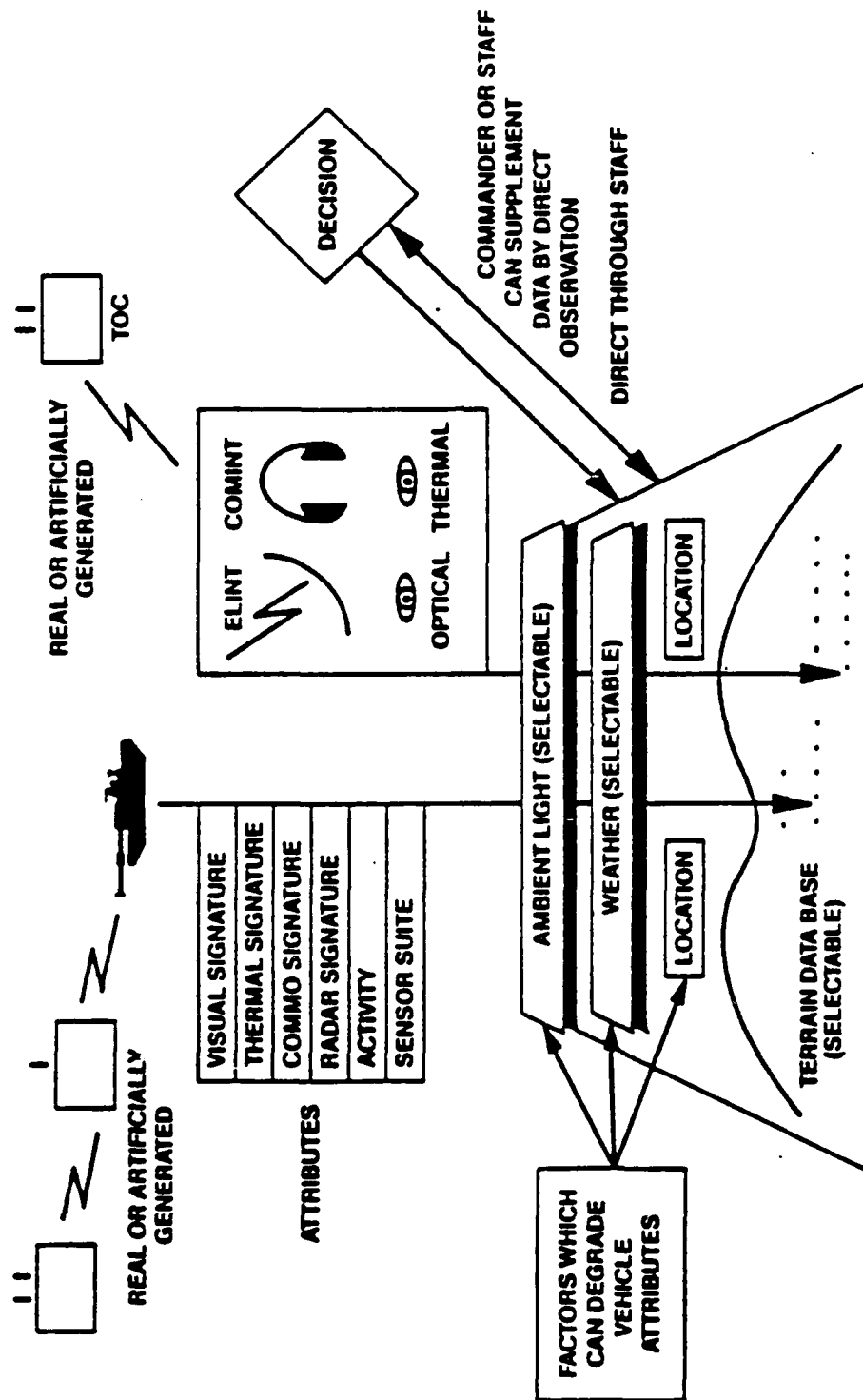
- **Current System**
  - **OPFOR Regiment (-) vs BLUFOR Battalion (-)**
  - **300 vehicles**
- **Expansion in Two Phases, each phase exhibits**
  - **10 times Vehicles (3000 and 30000)**
  - **5 times Units**
  - **10 times Increase in cognitive complexity**
  - **100 times Increase in Interactions**
- **Two major classes of scaling Issues.**
  - **Number of simulation objects, combinatorics of Interaction.**
  - **System becomes dominated by cognitive factors at high command levels.**



# DEFENSE SIMULATION INTERNET



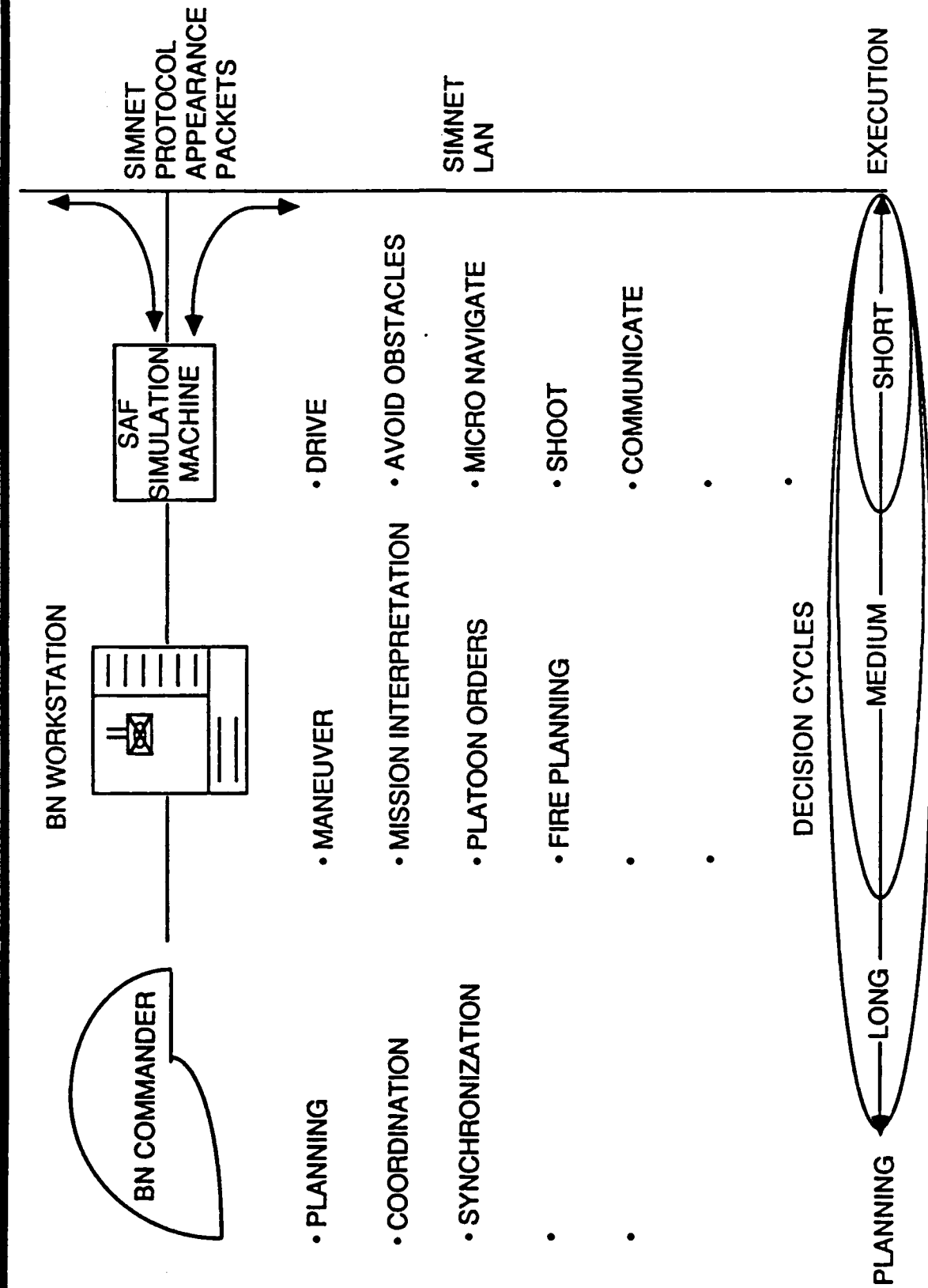
# ATTRIBUTES OF THE BCIP SIMNET BASED BATTLEFIELD



## WHAT IS DIFFERENT HERE?

- EACH SIMULATED FUNCTION/SYSTEM HAS REAL WORLD ATTRIBUTES
- MAN-IN-THE-LOOP AT EVERY VITAL DECISION POINT
- INTEGRATED BATTLEFIELD-INDIVIDUAL MANNED SYSTEMS & WORKSTATION CONTROL INTERCHANGEABLE
- THESE DIFFERENCES MEAN THAT OPPOSING COMMANDERS "SEE" THE BATTLE AS IN ACTUAL COMBAT

# SAF Concept



Advanced Simulation Division

## **Typical Sequence**

- 1. Conduct battlefield reconnaissance in simulator.**
- 2. Receive operation order.**
- 3. Input operation order to SAF workstation.**
- 4. Position self in TOC or simulator.**
- 5. Receive contact report (from workstation or manned simulator).**
- 6. Report to regiment or brigade (voice, paper).**
- 7. Obtain combat support or combat service support  
(automated via workstation or via comms to other warfighters).**



## **Soldier Machine Simulation Spectrum**

- SAF simulates vehicles, weapons, crews, staffs.

**Machine  
simulation**

- SAF vehicles and weapons have same external performance and appearance as manned simulators.
- SAF vehicles and weapons have simplified internal damage models (catastrophic, mobility, firepower, and comms kills) compared to manned simulators.
- Simulated SAF vehicle crew members reactively and proactively apply battle drills and combat SOPs.
- Simulated SAF command staffs reactively and proactively apply command and leadership functions, subject to supervisory control by human commanders.
- Human commanders fight to win and supervise/C2 software subordinates.

**Man  
in the  
Loop**

**Advanced Simulation Division**





## **Gestalt System The Human Component**

- **The SAF human commander**
  - **Is in supervisory control of automated subordinate staffs and weapon systems in a real time situation.**
    - **can control downwards when subordinate software is unable to maintain tactical realism.**
  - **must fight to win.**
  - **cannot subvert battlefield physics.**
  - **controls assets via a simulation of C3I.**
  - **reports upwards to a fully manned TOC.**



## **The Gestalt System The Automated Component**

- **Automated control achieved using mind/body paradigm.**
- **Mind is the Tactical Action Representation Language used for building missions.**
  - **TARL is a hierarchical contingent procedural language.**
  - **TARL constructs are executable mission descriptions (plan representations) for agents of the simulation.**
  - **Contingency construct permits arbitrary level of detail to be built on the fly when responding to environment.**
- **Editor provides interface to graphical representation of mission descriptions.**
- **Body is a set of SOPs coded at each simulation agent.**



## **White Box Approach**

- **Three levels of SAF simulation**
  - **vehicle and weapons systems parameters.**
  - **vehicle and unit behavior/tactics parameters.**
  - **human commander generated missions.**
- **Each has a text/graphical editor**
  - **Models editor:**                      **used by Battle Master.**
  - **Tactical action editor:**        **used by the developer**  
   **(user or contractor).**
  - **Commanders Interface:**    **used by the human commander.**
- **Editors create a white box system**
  - **examine parameters.**
  - **modify parameters.**
  - **user becomes responsible for the underlying parameters.**



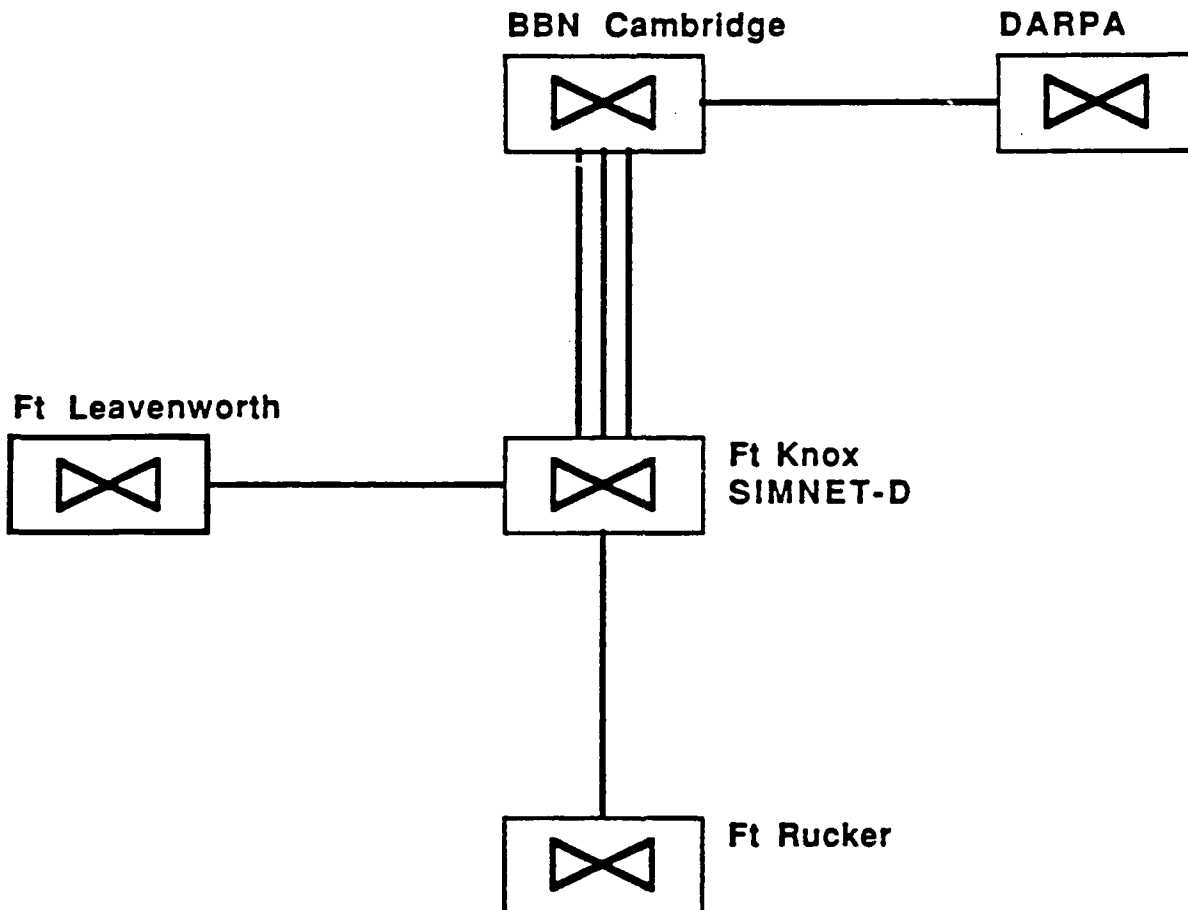
## SAF 3.X OBJECTIVE

Transform System Demonstrated in March (SAF 3.0) into Reliable System for Transition to Army.

SAF 3.X Will Support:

- Troop Training
- Combat Development Experiments

## Long Haul Network Architecture



### Legend



Long Haul Gateway Butterfly

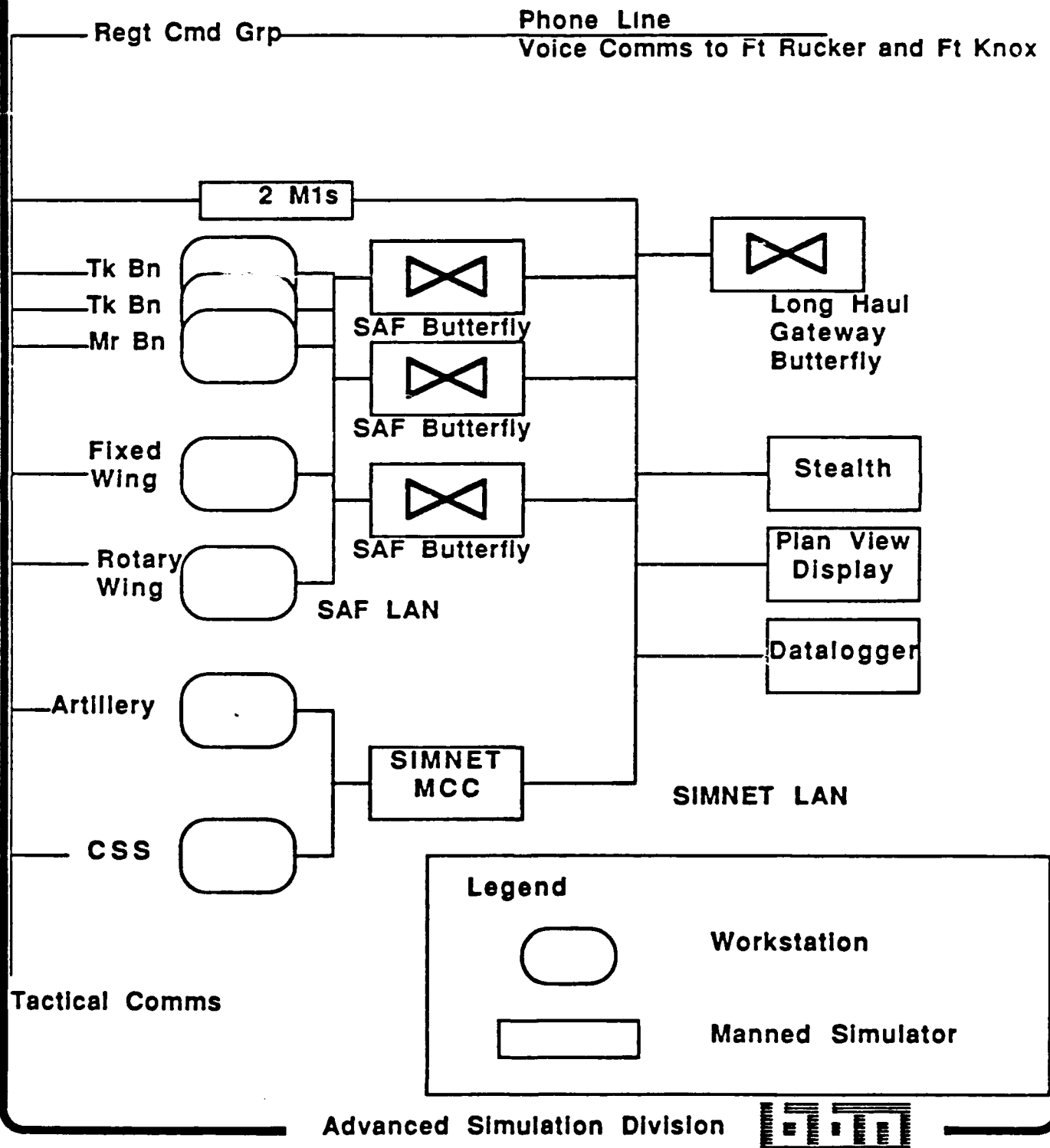


Long Haul Network 56 KB Data Line

Advanced Simulation Division



# OPFOR at BBN Cambridge

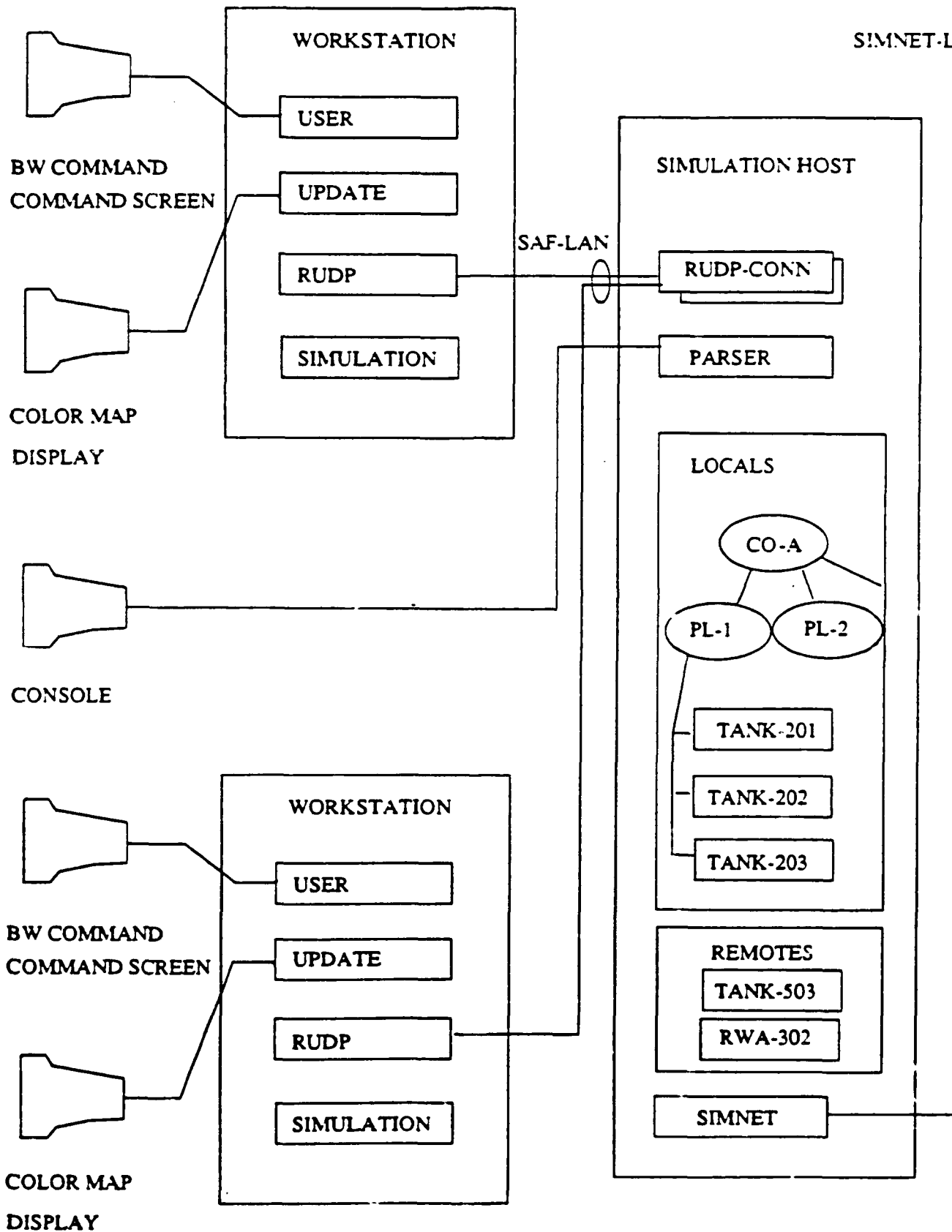


## ENHANCEMENTS

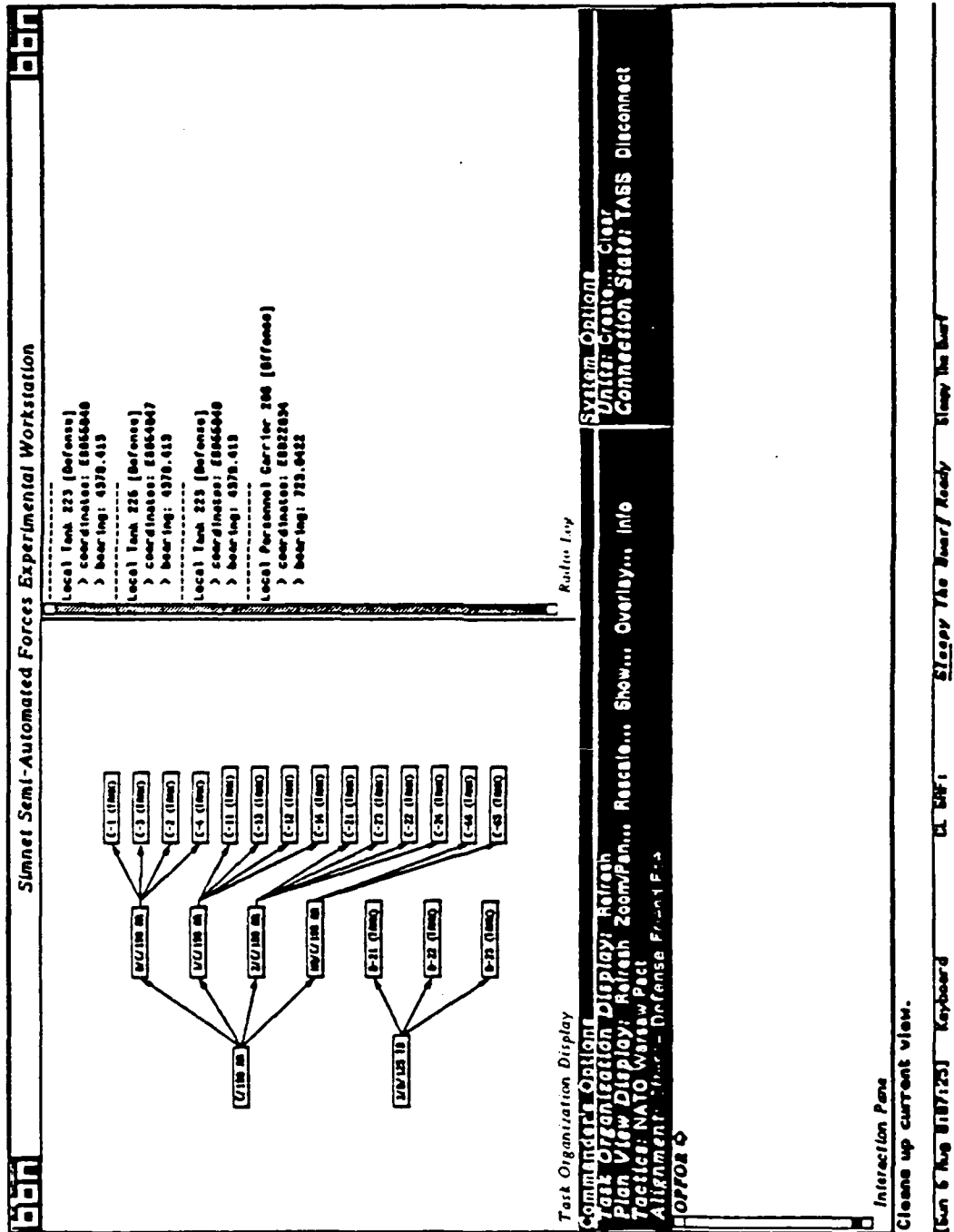
- Increase Numbers of Vehicles
- More Intuitive Interface for Soldiers
- Fair Play
- Increase Vehicle Intelligence
  - Standard Operating Procedures
  - Terrain Reasoning
- Ability to Task Organize
- Store and Retrieve Scenarios
- Dismounted Infantry
- Mixed Manned and Automated Units
- Reliable and Robust
- No Proprietary Code

# SAF ARCHITECTURE

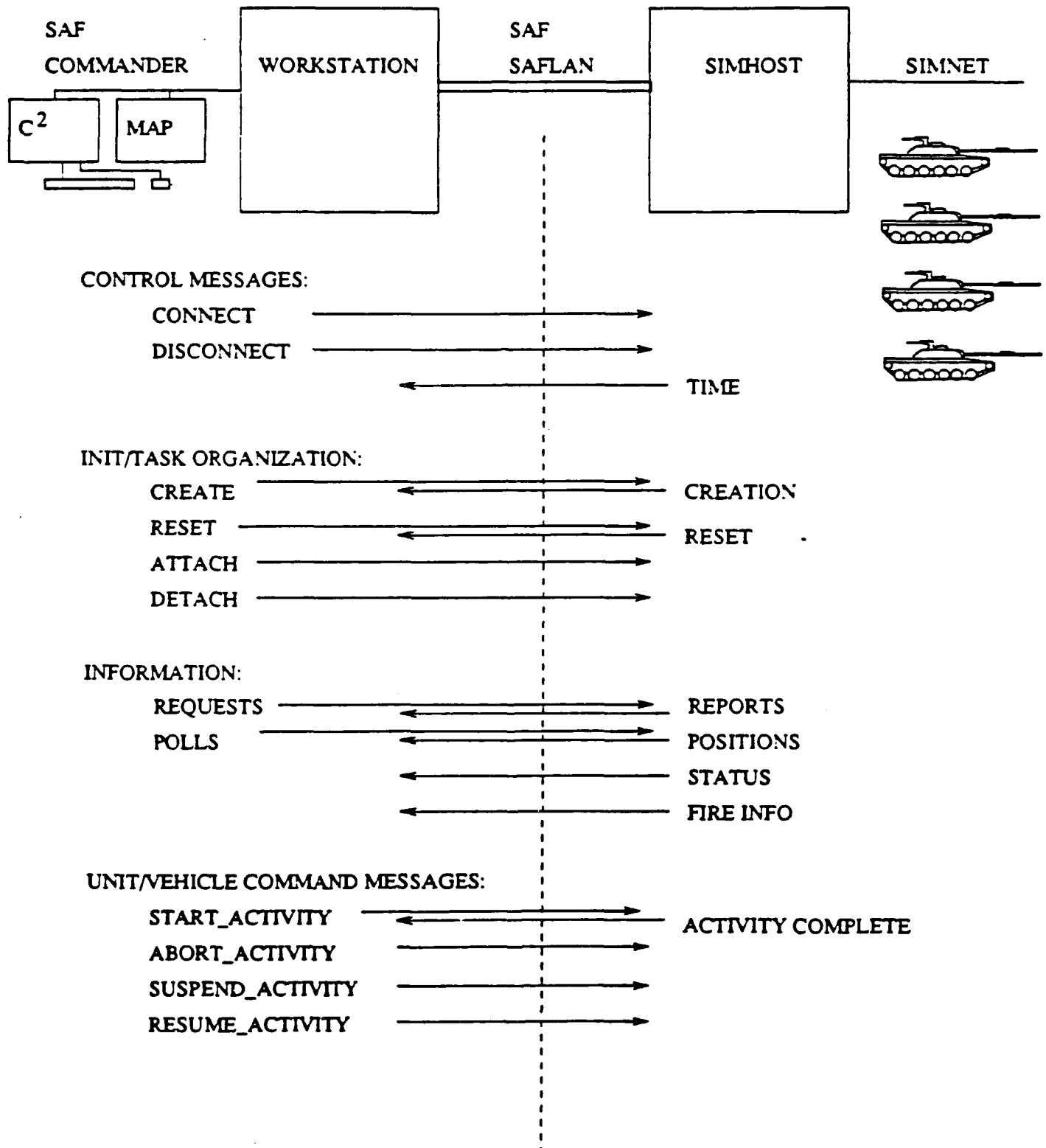
SIMNET-LAN



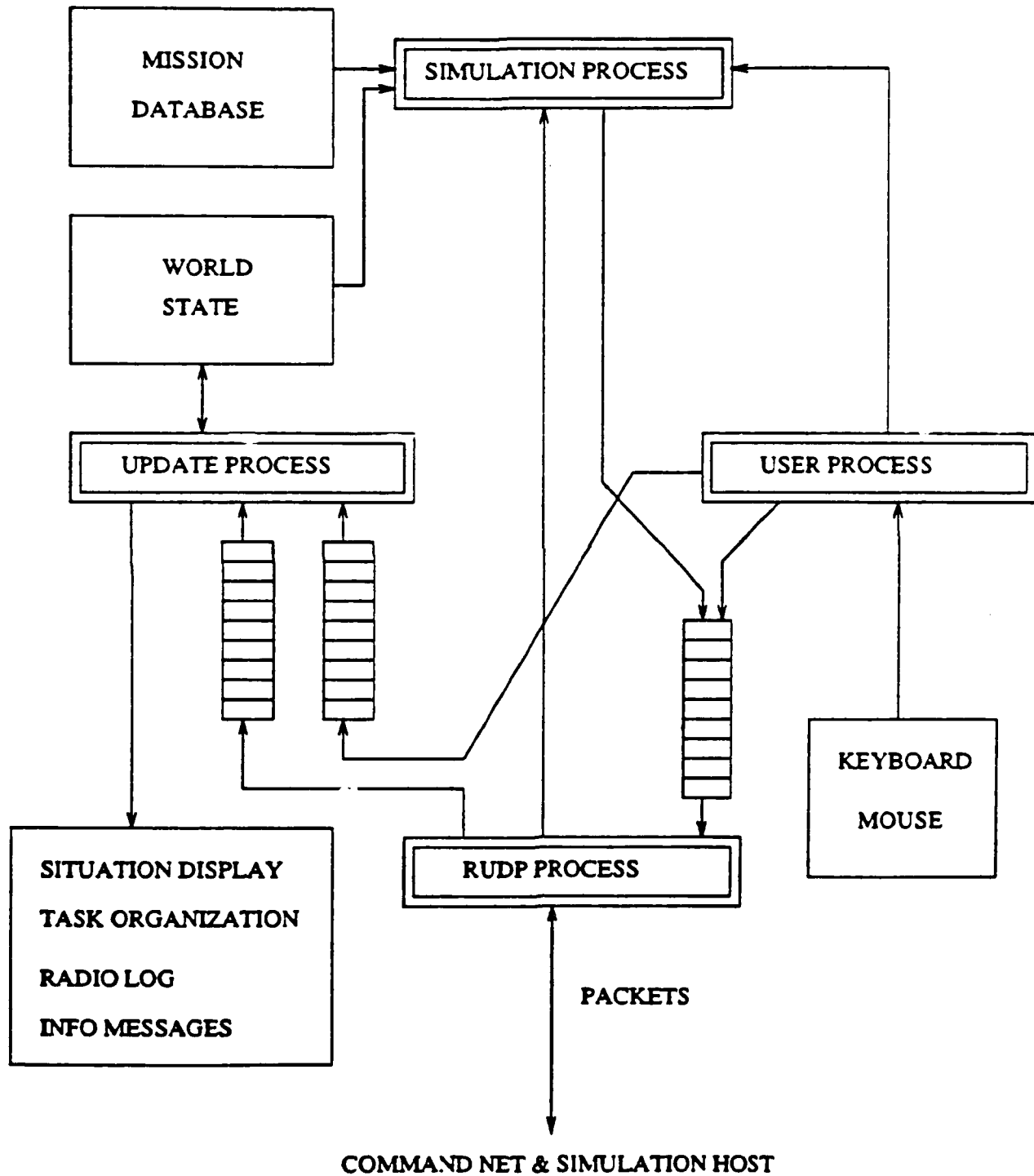




# WORKSTATION SIMHOST COMMUNICATIONS



## WORKSTATION ARCHITECTURE



Simnet Semi-Automated Forces Experimental Workstation

No Command Post

Radio Log

Task Organization Display

Commander's Option

Task Organization Display: Refresh

Plan View Display: Refresh ZoomPan: Resellon: Show: Overlay: Info

Tactics: NATO Warsaw Pact

Alignment: Offense Defense Friend Foe

OPFOR

Requesting Creation On SIMNET LAN.

OPFOR

Trying Host HAMMER (0)

Connected to HAMMER

Reading Configuration Data ... Done.

OPFOR

Requesting Creation On SIMNET LAN.

OPFOR

Created Vehicles On SIMNET LAN, Commencing Local Creation.

Initiation From File

System Options

Unit: Create... Clear

Connection Status: HAMMER Disconnect

Time

User Input

LL Sid :

[Thu 15 Jun 10:00:50] Keyboard

## WORKSTATION COMMANDS

- System Commands
  - Connect/Diconnect From Simhost
  - US Units/Russian Units
  - Select Team
  - Create/Clear Units
- Map Commands
  - Zoom, Pan, Rescale, Refresh
  - Show/Hide: Roads, Water, Trees, Contours, Grid
  - Overlays: Draw, Save, Restore and Edit
- Unit Commands
  - Fire Control: Skill, Range, Fire Permission
  - Regroup
  - Face Direction
  - Assign, Show, Suspend, Resume, Abort Mission

## ASSIGNING A MISSION

- Select A Mission From Menu
  - March
  - Attack
  - Defend
  - Delay
  - Resupply
  - Withdraw
- Prompts for Parameters
  - Routes and Roads
  - Control Measures from Overlays
  - Speeds ...
- Select Time to Start or Store as Contingency

## A MORE SOLDIER FRIENDLY INTERFACE

- Use Command Representations Familiar to Soldiers
  - Unit Symbols in Task Organization
  - Use OPORD Format to Access Operations
  - Extend Use of Control Measures
  - Provide More Overlays
- Separate Command, Initialization, and System Functions
- Provide More Feedback and Status Information

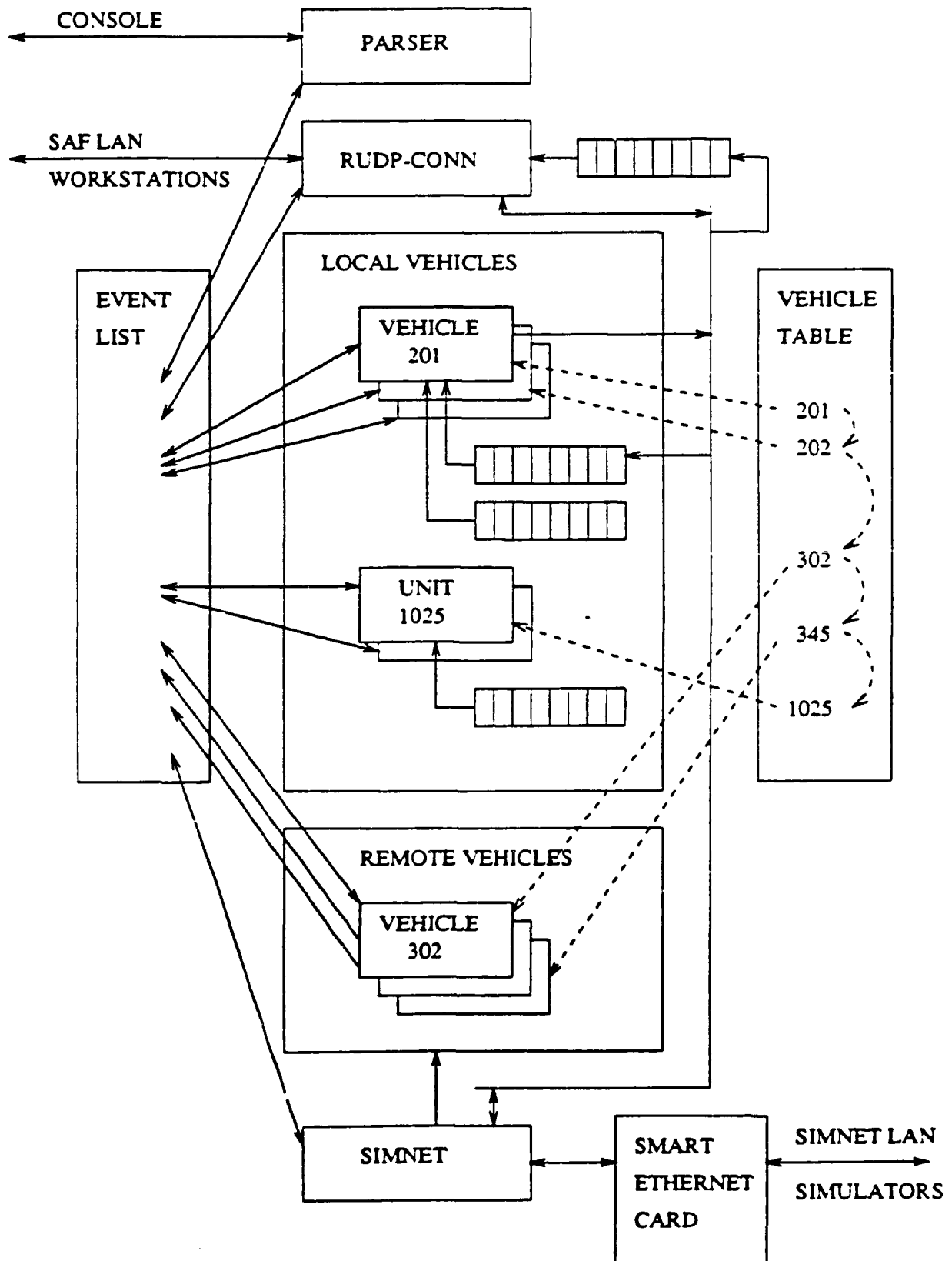
SIMNET Semi-Automated Forces Workstation (Version 3.x)		Name of 1st Radio Net		Name of 2nd Radio Net		Name of 3rd Radio Net	
401st Motorized Rifle Battalion		Message Log					
<p>Task Organization</p> <p>D-34</p>							
<p>Options</p> <p>Save Exercise</p> <p>Take Immediate Action</p>		<p>Situation</p> <p>Enemy (Intelligence Overlay)</p> <p>Friendly (see written orders)</p> <p>Attachments/Detachments</p> <p>Mission (see written orders)</p> <p>Execution</p> <p>Concept of Operations (see written orders)</p> <p>Operations Overlay</p> <p>Subordinate Tasking</p> <p>Fire Support</p> <p>Air Support (call FWA/RWA Commander)</p> <p>Air Defense (ADA Overlay)</p> <p>Coordinating Instructions</p> <p>Administration &amp; Logistics (call ALOC)</p> <p>Command, Control, &amp; Communications</p> <p>CEOI (Communications Plan)</p> <p>Location of Command Post</p>		<p>Options</p>			
Workstation Instructions		Workstation User:		SAF Commander		Battle Master	
						System Operator	



## ROUTE PLANNING

- Subordinate Unit Routes
  - Battalion Boundaries to Company Routes
  - Translate Company Routes to Platoon Routes
  - Check for Routes Crossing Water
- A\* Route Planner on Road Networks

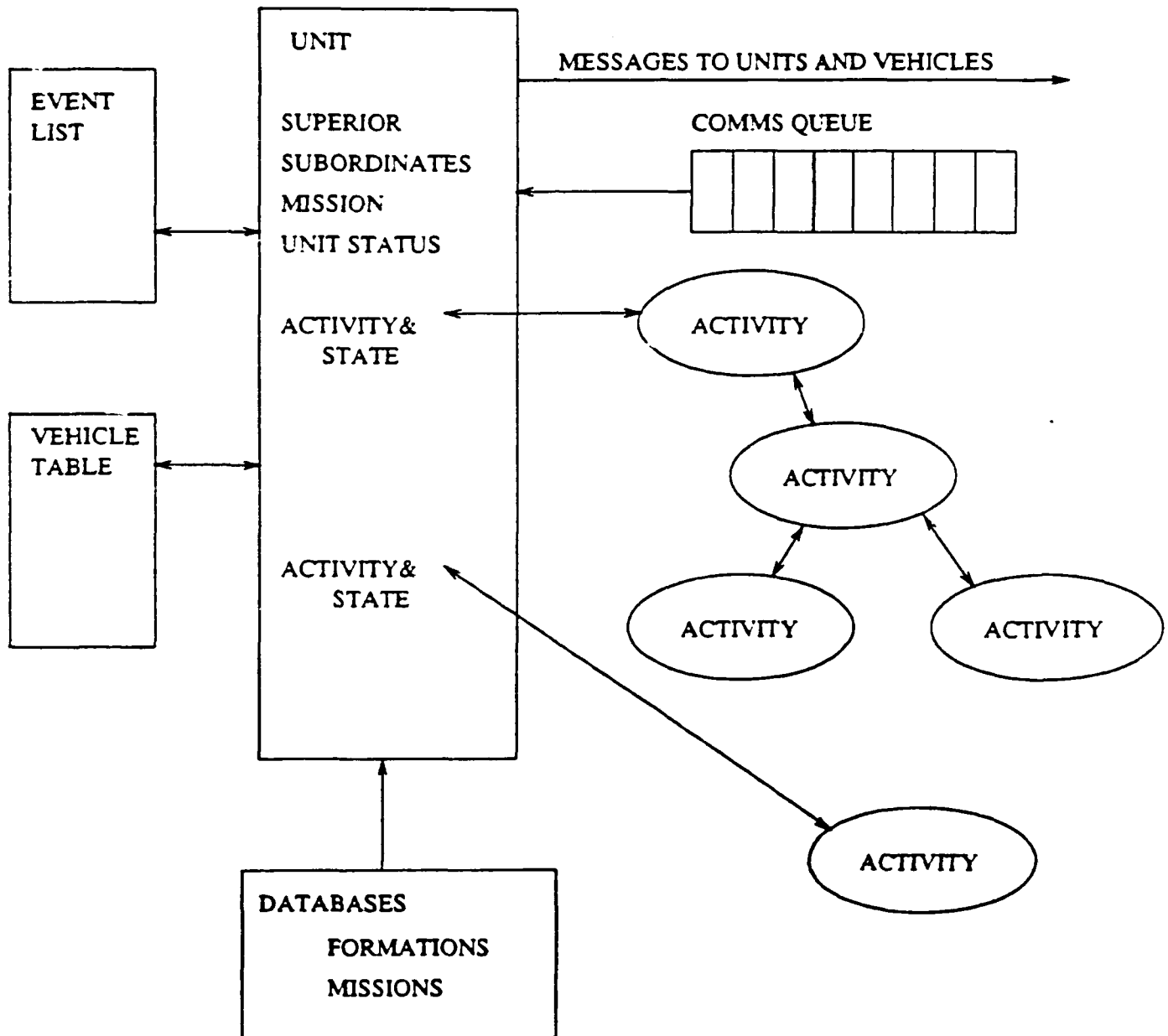
# SIMULATION HOST ARCHITECTURE



## UNIT FUNCTIONS

- Represent Unit Structure
  - Promotion
  - Task Organization
- Distribute Orders
  - Tasks and Missions
  - Fire Parameters
  - Requests
- Send Back Reports
  - Filter
  - Aggregation
- Coordinate Subunits
  - Fire Zones
  - Movement

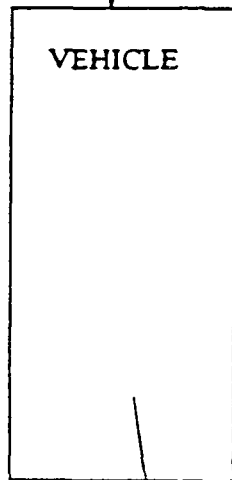
## UNIT SIMULATION



# COMMANDS AND ACTIVITIES



COMMANDS TAKE THE FORM OF  
START ACTIVITY (NAME, ARG1, ...)



INTERPRETTED  
ACTIVITIES

BASIC  
ACTIVITIES

PROVIDE CONTROL  
BY SPAWNING AND  
TERMINATING CHILD  
ACTIVITIES

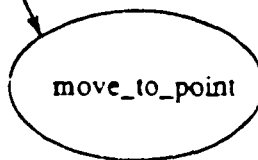
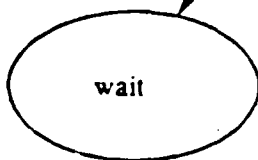
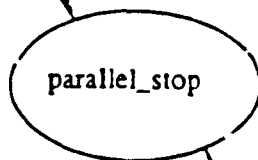
PROVIDE STATE  
CHANGE BY EXECUTING  
C-FLAVORS METHODS

TYPES

INCOMPATABLE  
ACTIVITIES

SEQUENTIAL  
PARALLEL  
PARALLEL STOP  
CYCLIC  
CONDITIONAL  
DO\_LIST

SUSPENDED OR  
ABORTED BY CLASS



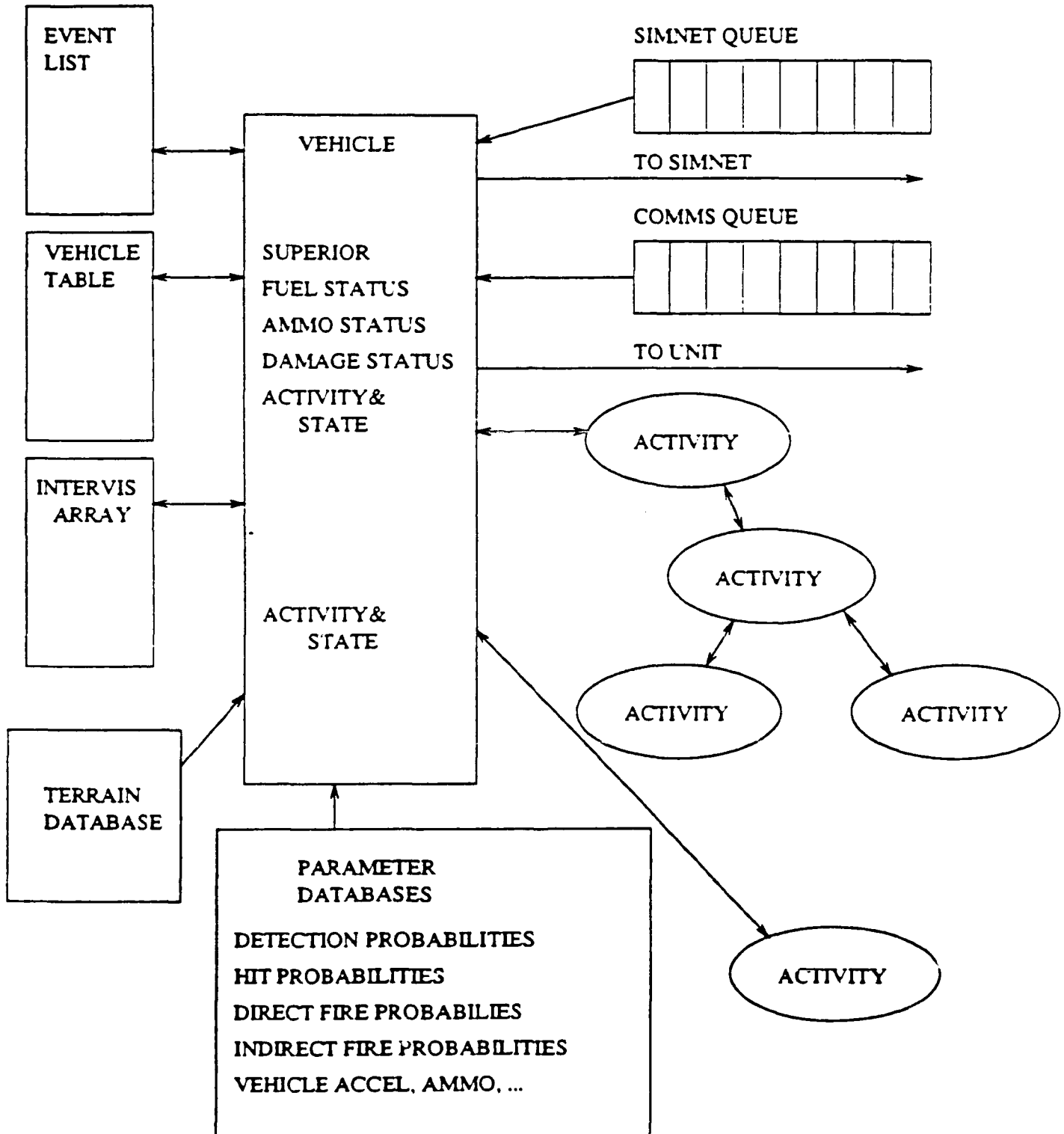
```

(define_activity keep_station ()
  ((class . maneuver))
  (cycle
    (update_station)
    (parallel_stop
      (wait 5000)
      (move_to_point))))
  
```

## VEHICLE FUNCTIONS

- Look
  - Intervisibility
  - Detection and Identification
- Move
  - Go to Point
  - Avoid Obstacles and Collisions
- Shoot
  - Target and Weapon Selection
  - Load, Track, and Fire
- Communicate
  - Receive Commands and Requests
  - Trigger and Send Reports
- Logistics
- Damage

# VEHICLE SIMULATION



# VEHICLE DYNAMICS

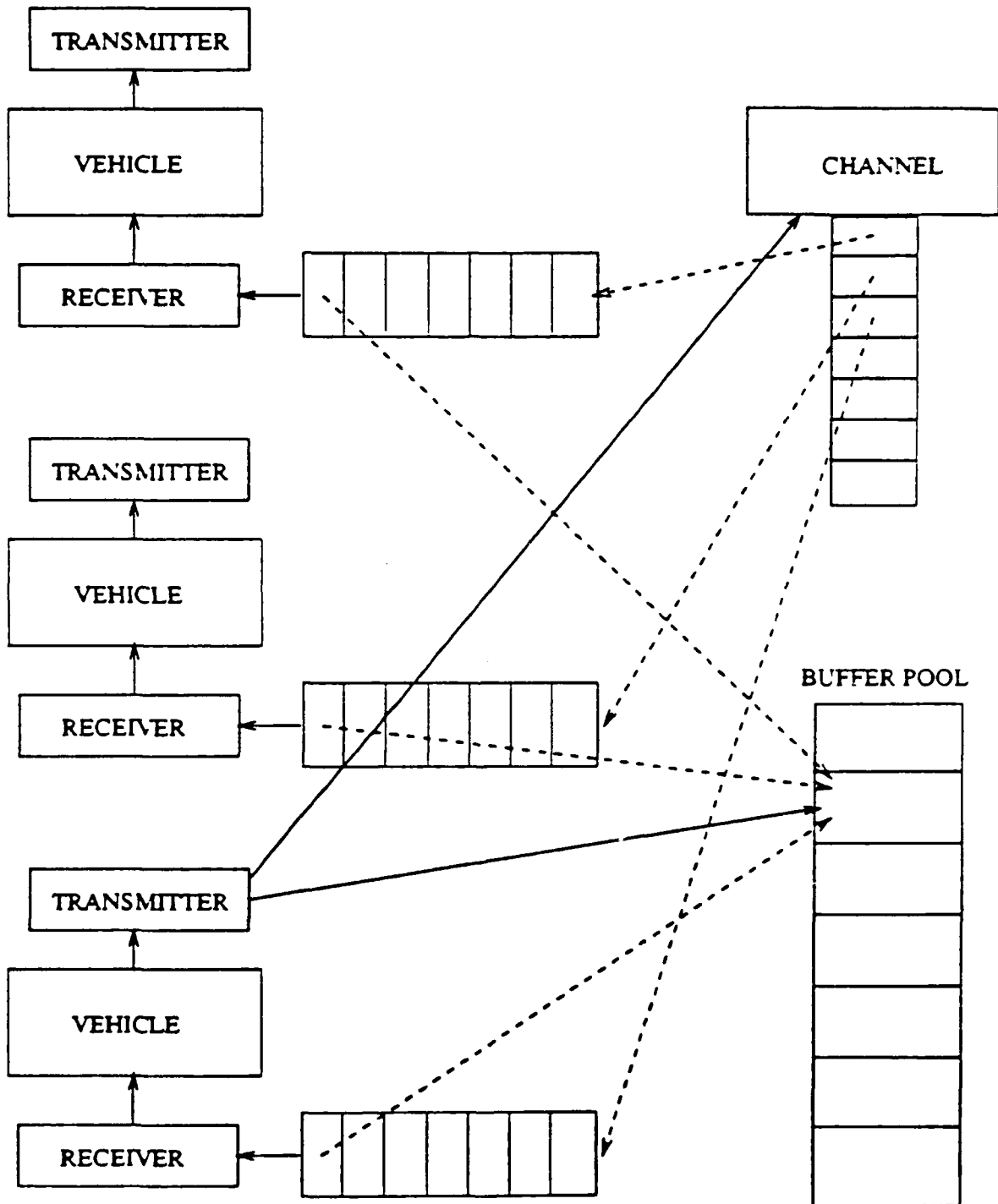
- Ground Vehicles
  - 8 Degrees of Freedom
    - Turret Azimuth and Gun Elevation
  - Integrate Azimuth, X, Y, Z
  - Limit Acceleration, Speed, and Turn-rate by Vehicle and Soil Type
  - Fit Pitch and Roll to Match Soil
  - Collision Checks
- Air Vehicles
  - 6 Degrees of Freedom
  - Nap Of the Earth Look Ahead



# VEHICLE AND UNIT MOVEMENT

- Vehicles
  - Move to Point
  - Keep Station
  - Obstacle and Collision Avoidance
- Platoons
  - Follow route
    - \* Issue Waypoints to Leader
    - \* Wings Keep Station on Leader
  - Follow Road
    - \* Issue Waypoints to All Vehicles
- Companies
  - Issue Routes and Roads to Platoons
- Time Based Coordination
- Bridge Crossing
- Promotion

# RADIO COMMUNICATIONS



## Performance Problems:

### MOVE: Collision & Obstacle Avoidance.

- Potential collisions with obstacles, and all other vehicles.
- $O(N^2)$  problem.

### SHOOT: Target Acquisition.

- All other vehicles are potential targets.
- Visibility is a function of terrain.
- Manned simulators have special hardware (Z-buffer) which determines intervisibility as a by-product of display.
- The human soldier acquires targets from visible vehicles.
- SAF Simhost has no special h/w. It must perform *polygon intersections* to determine intervisibility.
- SAF Simhost uses a detection model (arcs of attention) to acquire targets.
- $O(N^2)$  problem.

### COMMUNICATE: Inter-vehicle, inter-machine communications.

- Workstation  $\iff$  Simhost Communications.
- Simhost  $\iff$  SIMNET Communications.
- Unit  $\iff$  Unit Communications.
- $O(N)$  problem.

## Processing Requirements

All #s as percent of time during whole run.

### MOVE:

- 16.4 dynamics
  - 10.3 vehicle placement
  - 6.1 acceleration, etc.
- 11.2 collision avoidance
- 9.2 collision detection
  - 8.0 other vehicles
  - 1.2 bounding volumes
- 7.8 route following
  - 4.6 bounding volume avoidance
  - 1.7 choose velocity
  - 1.0 station keeping lookahead
  - 0.3 close-enough checks
  - 0.2 station keeping idle

### I/O:

- 7.4 sending appearance packets

### SHOOT:

- 6.3 intervis
  - 6.3 point-to-point computation
  - 1.3 choosing vehicles to test
  - 0.7 detection database lookup
  - 0.8 detection computation
- 6.1 targeting
  - 2.9 maintain target list
  - 1.7 moving turret
  - 1.0 scanning
  - 0.3 tracking
  - 0.2 creating impacts

### COMMUNICATE:

- 2.9 communications
  - 2.7 vehicle-to-vehicle
  - 0.2 simnet-to-vehicle

### OTHER:

- 32.7 other functions

## **Performance Optimizations:**

### **MOVE: Collision & Obstacle Avoidance.**

- We use hybrid data structures for storing our vehicle information. They are efficient for both random-access and iteration.
- We cache vehicle location information in tables to eliminate overhead of sending messages.

## **SHOOT: Target Acquisition:**

There are several levels of optimization performed to help performance.

### **Eliminating Unnecessary Intervisibility Checks:**

- Cost of detection model is in program-measurement noise.
- Cost of intervisibility calculation is not (mean of  $\approx 8.25$  msec).
- So, we run the detection model first.
- This saves 10-35% of intervisibility calculations.

**Optimization of Remaining Intervisibility Checks:** Intervisibility built on top of terrain database which is optimized for intervisibility calculations.

### **Terrain Database Patch Guards:**

- Patch guards are pre-computed minimum and maximum elevations for each 500 meter-square terrain patch.
- These are cached, and lines between eyepoint and target are tested to see if it is necessary to check individual terrain polygons.
- Their use eliminates 50-70% of accesses to individual terrain patches for polygon intersection.

### **Terrain Database Patch Cache:**

- Individual terrain patches, if they must be referenced, are read off disk and are cached in memory.
- They are flushed on a Least Recently Used bases.
- The hit-rate for this cache is highly variable.

### **Simulation Host Computer Cache:**

- Most disk drivers have disk block caches.
- This can save actually waiting to read magnetic media.

**COMMUNICATE: Inter-vehicle, inter-machine communications.**

- We have efficient queueing packages.
- We have a buffer package.
- These allow us to avoid copying wherever possible.

## Organization of Simhost Software:

### Simulation

- Software is written using OOP ('C'-Flavors).
  - Multiple-Inheritance (pre-dates C++ multiple-inheritance)
  - Message-Passing
- Simulation is event-list-based.
- Items in event-list are (*Time Instance Message Datum*) tuples.

### Portability

Simulation runs on:

- Uniprocessors
- Multiprocessors (parallel-processor support code is conditionally compiled using C preprocessor `#ifdef` directive). We require:
  1. shared memory
  2. read-modify-write cycle
  3. UNIX "fork"-like process creation facility
- Program runs on/has run on:
  - MassComp 5500, 5600 RTU (System V based)
  - Sun 3/50,3/60,3/280 SunOS (BSD 4.1 based)
  - MIPS R/2000. UNIX (System V based RISC Machine)
  - BBN Butterfly running Chrysalis (Multiprocessor)
  - BBN Butterfly GP-1000, MACH UNIX (BSD 4.3 based Multiprocessor)



## Parallelism

### Why bother?

- There were no more cost-efficient uniprocessor solutions at the time we went to a parallel processing solution.
- Parallel-processors are scalable.
  - Important for cost-effective solution to differing site performance requirements.
  - Important if computational requirements are not known in advance.

## **What are the issues in parallel processor performance?**

### **Concurrency Control:**

Ensures correct operation of program. Especially with respect to I/O.

### **Load-Balancing:**

Ensures efficient use of resources.

### **Memory Contention:**

This has proved to be the most significant factor limiting scaling-up in shared-memory multiprocessors.

## SAF Simhost Approach to Parallel Processing

### Concurrency Control:

Parallelism occurs at the instance level. Concurrency is controlled on the message SEND operation.

- Two Version Two Phase Locking.
  - Public and Private copies of instance variables.
  - Locks:
    - Write
    - Certify (Read-inhibit)
    - Read
- Allows many concurrent read operations with one simultaneous write operation.

### Multiprocessor-capable I/O Facilities:

- Event-lists
- Buffer Pools
- Queues
  - Fast, Fixed-length
  - Slower, "Infinite"-length, doubly-linked

### Load-Balancing:

- Minimal Dynamic Load-balancing.
- We do not support object migration.

### Memory Contention:

- A given processing node hosts a set of instances.
- A given processing node has its own event-list.
- Certain information replicated on nodes:
  - some terrain database information
  - flavor method lists
  - vehicle tables
- Certain information distributed across nodes:
  - unit parameter databases
  - activities definitions
  - detection, hit, and damage models

## Using Geometry to Minimize $O(N^2)$ Problems:

### Root Cause of the $O(N^2)$ Problems:

- A given unit must check all other units for interactions.
- Try to dynamically group vehicles based on spatial relationships.
- Should make many functional areas of the program less expensive.
  - Intervisibility
  - Detection
  - Target Acquisition
  - Collision Avoidance
  - Indirect Fire

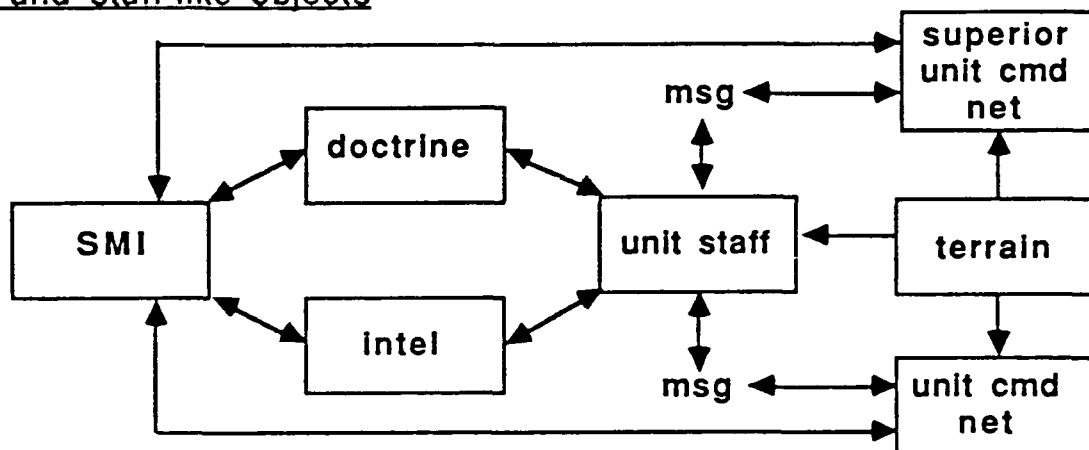
## **Critical Enabling Technologies**

- Critical enabling technologies are identified from a top level object oriented architecture of the domain.
- These technologies are of three types
  - Technologies which support the human commanders cognitive functions (monitor, assess, predict, plan, control).
  - Technologies which support execution (move, shoot, communicate, see).
  - Implementation dependent technologies (network communications, distributed simulation, parallel processing).
- Workstation based technologies, in support of the commander
  - Doctrinal Knowledge Representation.
  - Mission and Plan Representation and Execution.
  - Text Generation System.
  - Terrain Representation and Reasoning.
- These technologies designed to scale vertically to deal with cognitive functions.
- Additional technologies deal with combinatoric scaling.

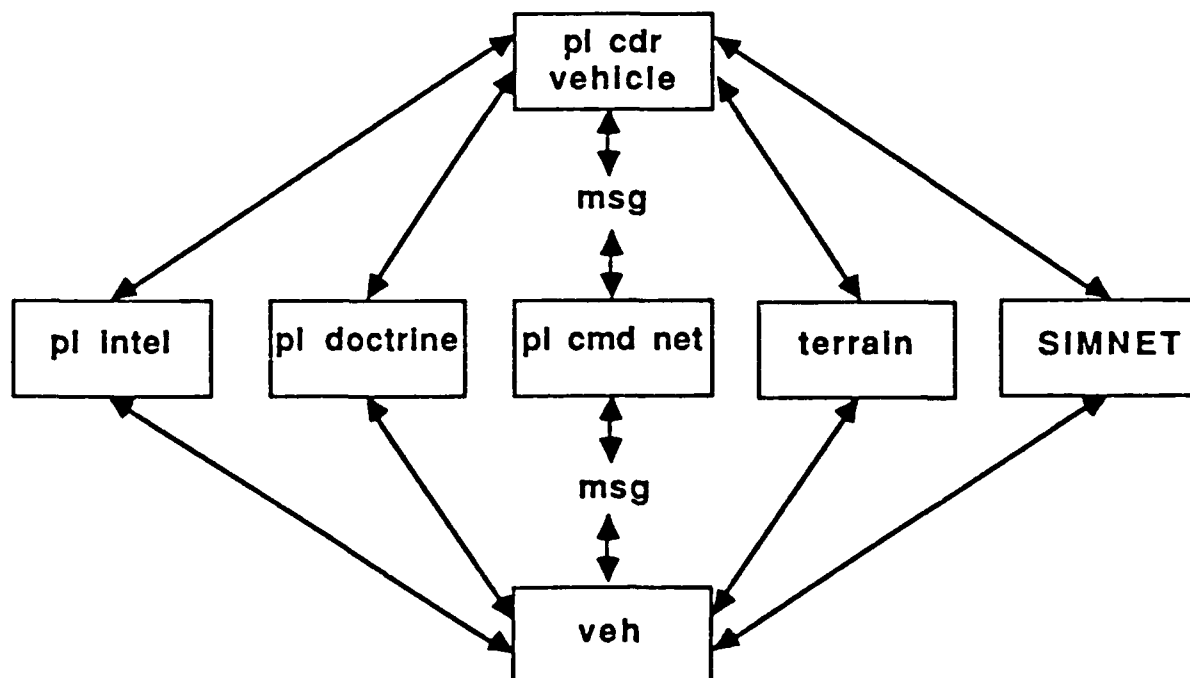


# Top Level Object Oriented Functional Architecture

## TOC and staff-like objects



## Platoon and platoon-like objects



**Tactical Action Representation Language  
(TARL)  
Components**

- **Simple Frame Language (SFL) for representation of declarative knowledge**
- **graphic editor for SFL**
- **Goal Plan Procedure (GPP) language for representation of procedural knowledge**
- **graphic editor for GPP**





## Knowledge Representation Environment

### Knowledge Representation Languages

Frame Language

Goal-Plan-Procedure Language

### SAF Knowledge Base

Simulation Objects

SAF Agents

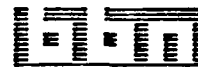
SAF Missions

### Graphic Knowledge Editors

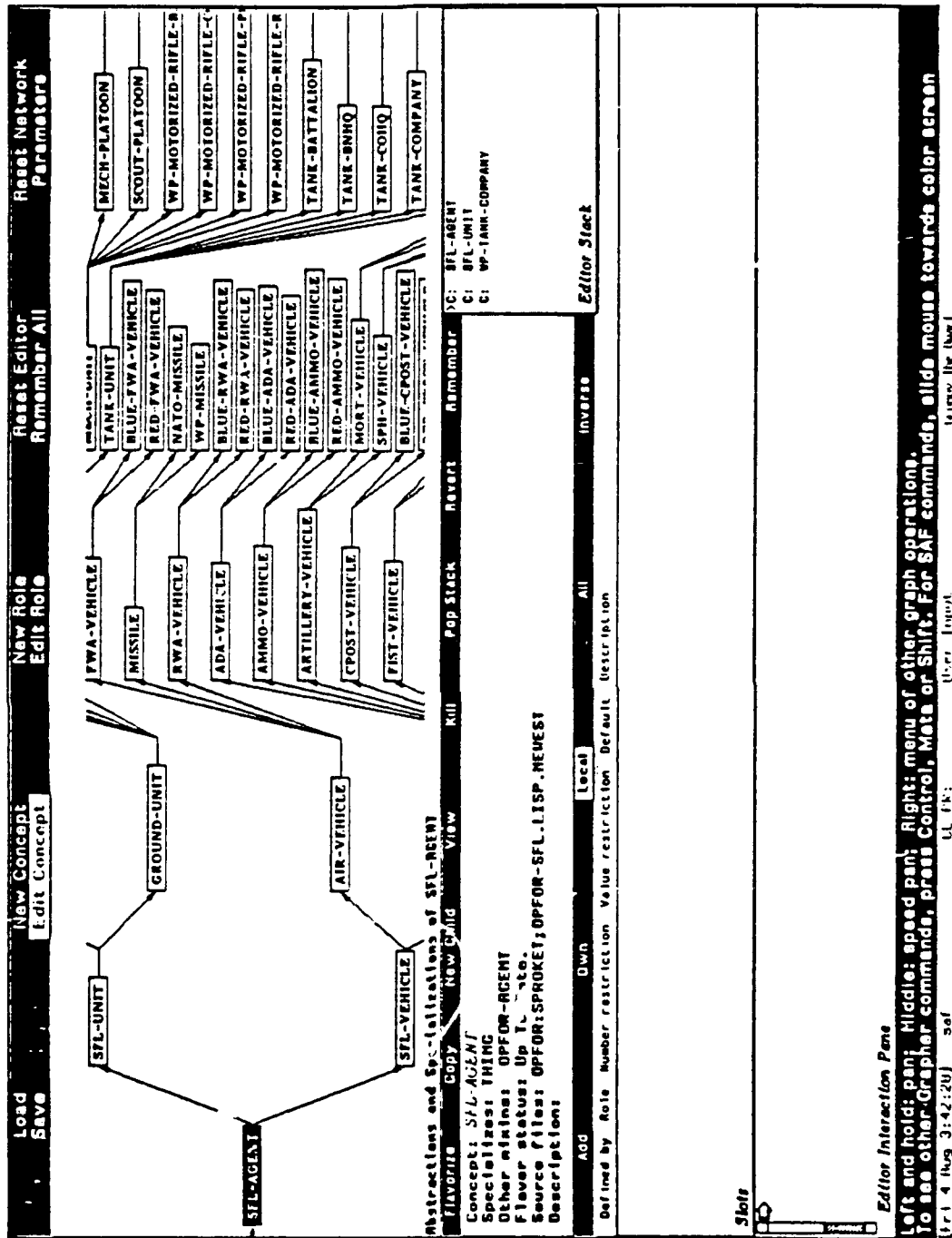
Frame Editor

Goal-Plan-Procedure Editor

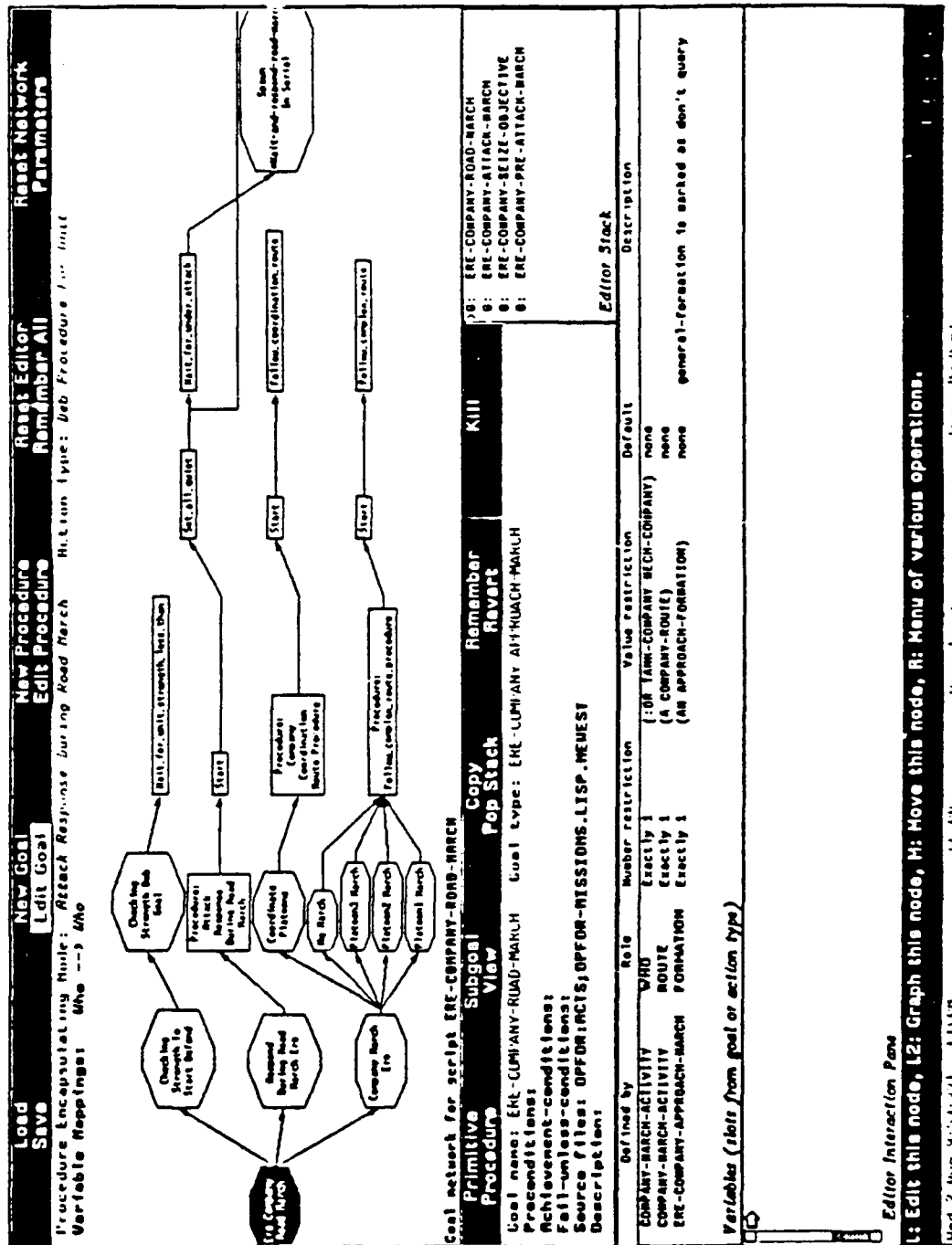
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# Concept SFL-AGENT



# Company Road March



**Motivation for SFL  
In Support of  
Object Oriented Simulation**

- **Symbolics Flavors are a good starting point**
- **value restrictions and default values lead to more expressive power**
- **the KL-ONE family of languages is a natural candidate**



**KREME  
as a  
Potential Candidate**

- **developed under DARPA sponsorship**
- **derivative of KL-ONE**
- **provides concept and role hierarchies**
- **concept slots have value and number restrictions, and default values**
- **provides a graphical editor for working with large concept hierarchies**
- **Includes a classifier**



## **Simple Frame Language (SFL)**

- **derivative of KREME and KL-ONE**
- **concept slots have value and number restrictions, and default values**
- **Includes the graphical editor for concepts and roles**
- **provides instances of concepts**
- **does not include the classifier**



## **Classifier Issues**

- **it would have been nice to include the classifier but it was not essential for development**
- **porting and maintaining the classifier was judged to be a black hole**
- **the classifier degrades interactive performance of the graphical editor in KREME**



## SFL Instances

- grounds instances as instances of Symbolics Flavors for performance
- value restriction and number restriction and not checked at run time
- provides standard Zmacs editing of behaviors (methods) for concepts

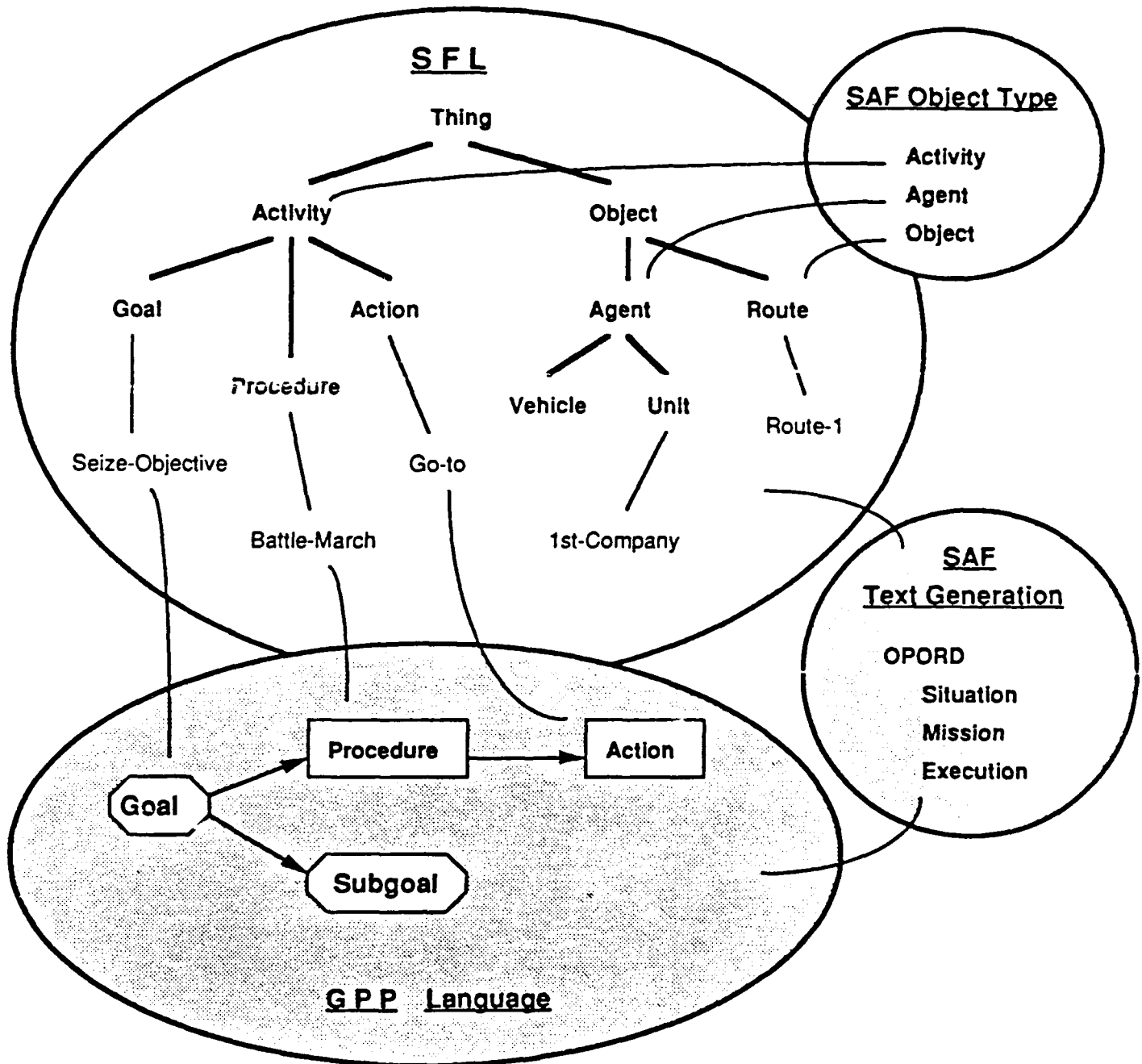


**SFL as a Central Resource  
in  
Semi-Automated Forces Development**

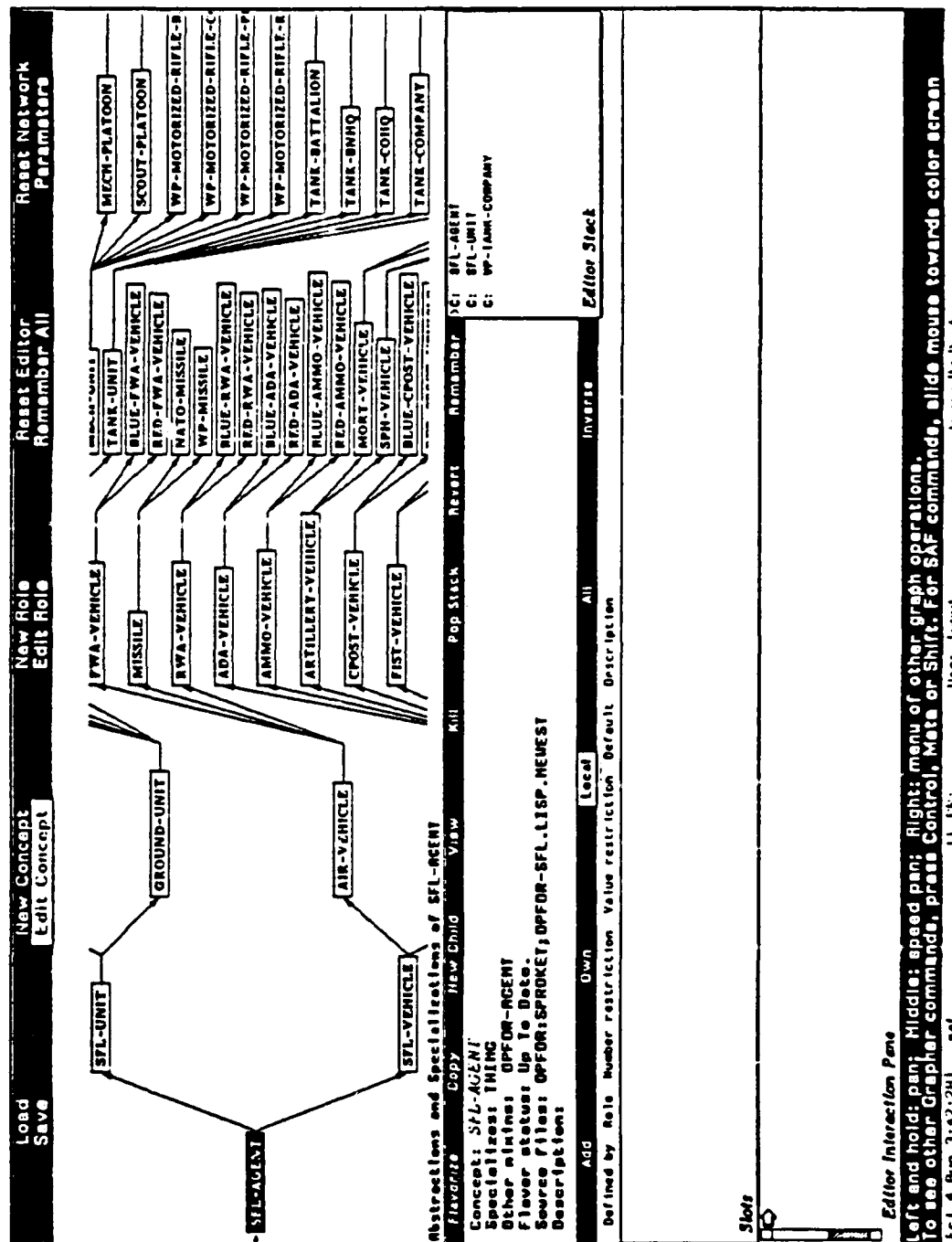
- **the SAF agents are instances of SFL concepts  
(e.g. tanks, tank platoons and companies, rotor wing aircraft)**
- **so are simulation objects such as the graphic overlays  
(e.g. unit boundaries, phase lines, routes)**
- **mission goals and procedures defined in the GPP language are  
based on SFL concept definitions**
- **text generation used in OPORD generation uses the SFL concept  
hierarchy**



## SFL as a Central Resource for SAF



# Concept SFL-AGENT



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**The Role of the  
Goal-Plan-Procedure (GPP) Language  
in SAF**

- **GPP provides a declarative representation of procedural knowledge**
- **used in SAF to define the contingent behavior of military units**
- **graphic editor provides a forum for interaction of system developers and subject matter experts**

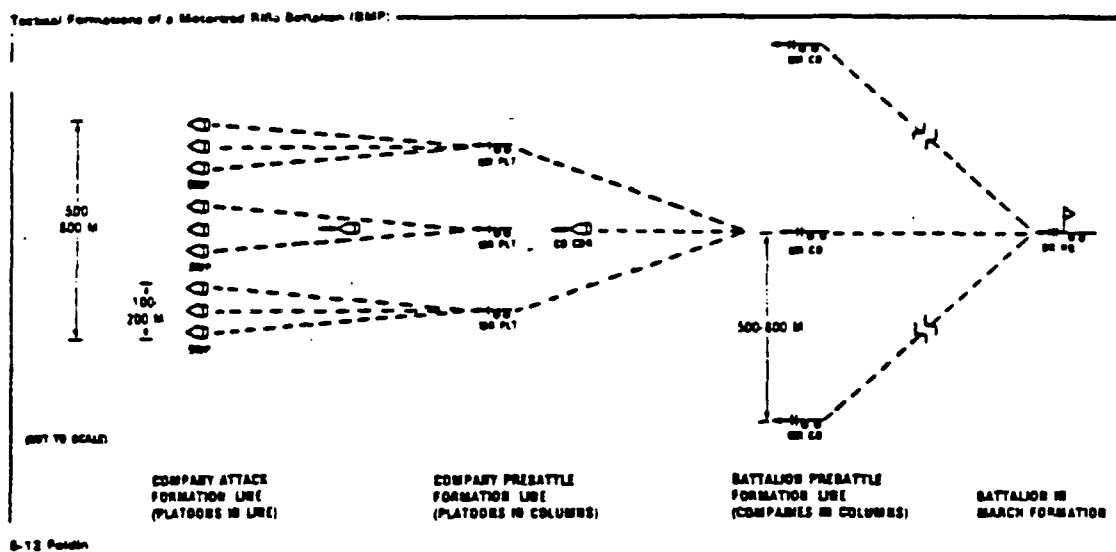


## **GPP as a Representation Language for Military Missions**

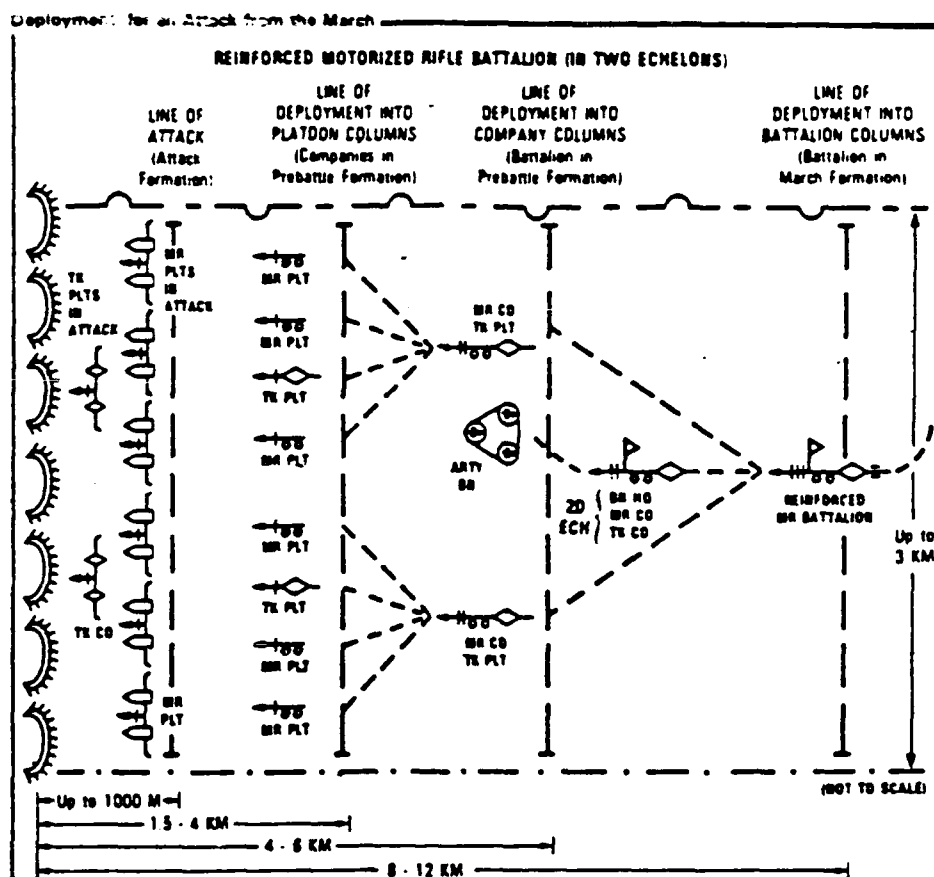
- **the objective of a mission is the achievement of a GPP goal**
- **the plan for achieving the goal is a refinement of the goal into subgoals and procedures**
- **following the hierarchy of military units, goal refinement frequently includes assigning subgoals to subordinate units**
- **procedures are knowledge level descriptions of how actions are to be executed in the SIMNET world**



# Tactical Formations of a Motorized Rifle Battalion (BMP) The Soviet Army: Operations and Tactics FM 100-2-1



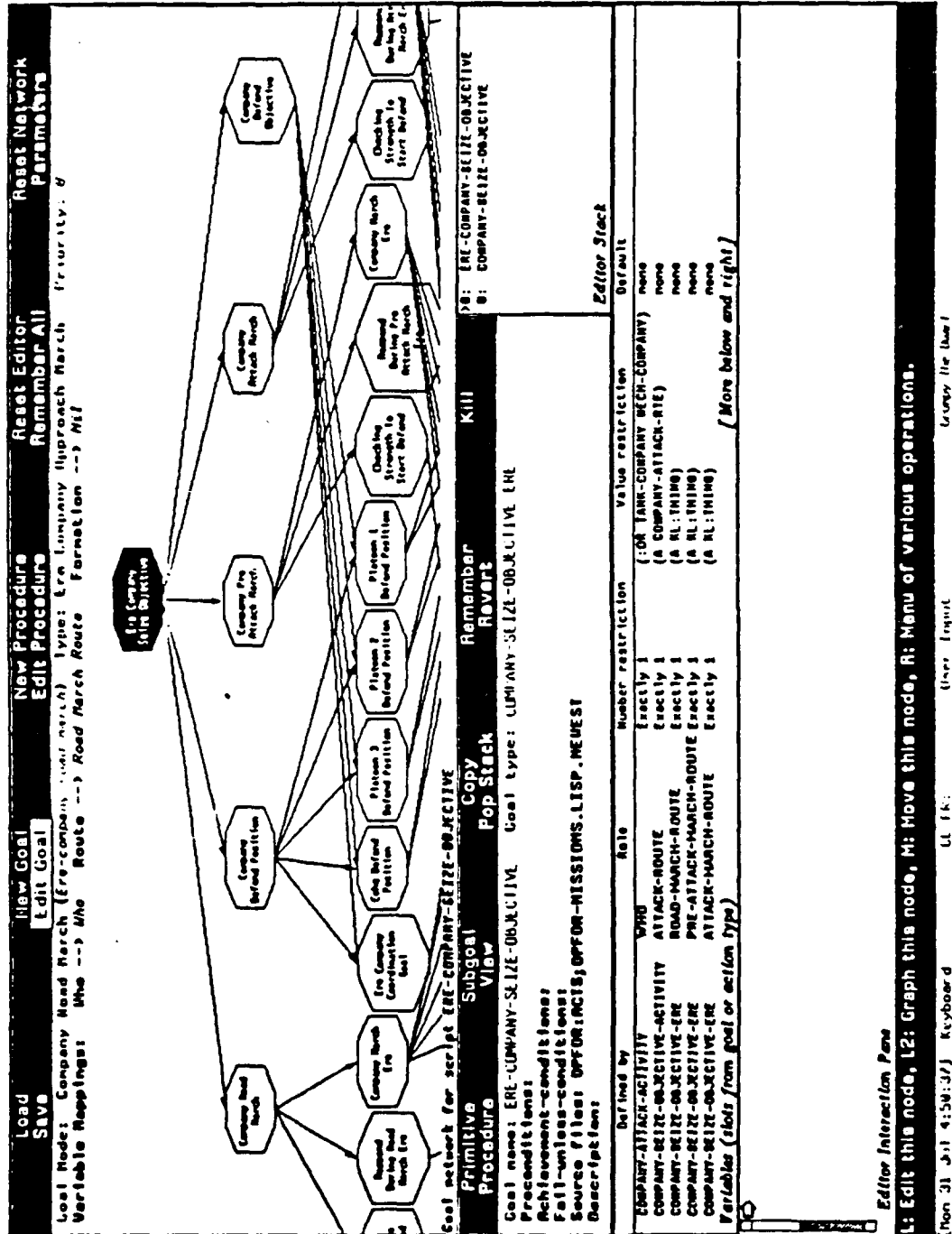
# Deployment for Attack from the March The Soviet Army: Operations and Tactics FM 100-2-1



B-25



## Company Selze Objective





# Company Seize Objective Precedence View

Load

Save

Low Goal

Edit Goal

New Procedure

Edit Procedure

Reset Editor

Remember All

Reset Network

Parameters

Precedence graph for goal ERE-COMPANY-SEIZE-OBJECTIVE

Primitive Procedure	Subgoal View	And Node	Copy Or Node	Remember Pop Stack	Kill Revert
Goal name: ERE-COMPANY-SEIZE-OBJECTIVE					
Preconditionals:					
Achievement-conditions:					
Fail-unless-conditions:					
Source files: OFFOR:ACTS, OFFOR:MISSIONS.LISP,HEWEST					
Description:					

Goal type: COMPANY: I/L-OBJECTIVE-LNL

Defined by	Rel	Number restriction	Value restriction	Editor Stack
COMPANY-ATTACK-ACTIVITY	OR	Exactly 1	{(OR TANK-COMPANY BECH-COMPANY)}	None
COMPANY-BEIZE-OBJECTIVE-ACTIVITY	ATTACK-ROUTE	Exactly 1	{(A COMPANY-ATTACK-RTE)}	None
COMPANY-BEIZE-OBJECTIVE-ERE	ROAD-MARCH-ROUTE	Exactly 1	{(A RL:TRING)}	None
COMPANY-BEIZE-OBJECTIVE-ERE	PRE-ATTACK-MARCH-ROUTE	Exactly 1	{(A RL:TRING)}	None
COMPANY-BEIZE-OBJECTIVE-ERE	ATTACK-MARCH-ROUTE	Exactly 1	{(A RL:TRING)}	None

Variables (dots from goal or action type) (More below and right)

Editor Interaction Pane

Left and hold: pan;

Middle: speed pan;

Right: menu of other graph operations.

To see other Grapher commands, press Control, Meta or Shift.

For SAF commands, slide mouse towards color screen

Mon 31 Jul 4:48:20

edutech

UL PR:

User Input

Copy The Data

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The screenshot displays the 'Editor Interaction Pane' with a hierarchical diagram on the left and a list of concepts on the right.

**Left Panel (Editor Interaction Pane):**

- Buttons:** Load, Save, New Concept, Edit Concept, New Role, Edit Role, Reset Editor, Remember All, Reset Network Parameters.
- Diagram:** A hierarchical tree structure showing the following nodes:
  - ERE-GOAL (connected to a small unlabeled box)
  - ATTACK-ACTIVITY (connected to ERE-GOAL)
  - COMPANY-ATTACK-ACTIVITY (connected to ATTACK-ACTIVITY)
  - COMPANY-SEIZE-OBJECTIVE-ACTIVITY (connected to COMPANY-ATTACK-ACTIVITY)
  - COMPANY-SEIZE-OBJECTIVE-ERE (connected to COMPANY-SEIZE-OBJECTIVE-ACTIVITY)

**Right Panel (Concepts):**

**Abstractions and Specializations of COMPANY-SEIZE-OBJECTIVE-ERE**

Favorite	Copy	New Child	View	Pop Stack	Revert	Remember	Company-SEIZE-OBJECTIVE-ERE
							SP-TANK-COMPANY
							SFL-ASSET
							SFL-UNIT

**Concepts:** COMPANY-SEIZE-OBJECTIVE-ERE  
**Specializations:** COMPANY-SEIZE-OBJECTIVE-ACTIVITY ERE-CORL  
**Other minimal:**  
**Flavor status:** Up To Date.  
**Source Files:** OFFOR,SPROKET,OFFOR-SFL,LISP,NEWEST  
**Description:**

**Editor Stack**

Add	Defined by	Own	Local	All	Inverse	Value restriction	Default
COMPANY-ATTACK-ACTIVITY	WHO					(FOR TANK-COMPANY RECH-COMPANY)	none
COMPANY-SEIZE-OBJECTIVE-ACTIVITY	ATTACK-ROUTE					(A COMPANY-ATTACK-RTE)	none
LOCAL	ROAD-MARCH-ROUTE					(A RL:THING)	none
LOCAL	PRE-ATTACK-MARCH-ROUTE					(A RL:THING)	none
ATTACK-ACTIVITY	ATTACK-MARCH-ROUTE					(A RL:THING)	none
	FORMATION					(A GENERAL-FORMATION)	none

**Footer:** Editor Interaction Pane

# Concept COMPANY-SEIZE-OBJECTIVE

Load	New Concept	Reset Editor	Reset Network
Save	Edit Concept	Remember All	Parameters
Concept: COMPANY SEIZE OBJECTIVE			
Specializations: ASSIGNABLE-TASK COMPANY-SEIZE-OBJECTIVE-ACTIVITY			

ATTACK-ACTIVITY

ASSIGNABLE-TASK

COMPANY-ATTACK-ACTIVITY

COMPANY-SEIZE-OBJECTIVE-ACTIVITY

COMPANY-SEIZE-OBJECTIVE

Abstractions and Specializations of COMPANY-SEIZE-OBJECTIVE

Abstract	Copy	New Child	View	Pop Stack	Reverts	Remember	SC
Concept: COMPANY-SEIZE-OBJECTIVE							C: COMPANY-SEIZE-OBJECTIVE
Specializations: ASSIGNABLE-TASK COMPANY-SEIZE-OBJECTIVE-ACTIVITY							C: GENERAL-FORMATION
Other minis:							C: COMPANY-SEIZE-OBJECTIVE-OBJ
Flavor status: Up To Date.							C: COMPANY-ATTACK-ACTIVITY
Source files: OFFOR:SPROKET,OPFOR-SFL.LISP,MEVEST							C: COMPANY-SEIZE-OBJECTIVE-ENE
Description:							C: WP-COMPANY-JOBS
							C: WP-TANK-COMPANY
							C: DOMAIN-ACTIVITY

Editor Stack (More below)

Add	Defined by	Own	Role	Local	Value restriction	Default
COMPANY-ATTACK-ACTIVITY	WHO				(OR TANK-COMPANY RECH-COMPANY)	none
LOCAL	OBJECTIVE				(A LINEAR-OBJECTIVE)	none
COMPANY-SEIZE-OBJECTIVE-ACTIVITY	ATTACK-ROUTE				(A COMPANY-ATTACK-RTE)	none
ASSIGNABLE-TASK	START-TIME				(A TIME)	none
ATTACK-ACTIVITY	FORMATION				(A GENERAL-FORMATION)	none

Slots [More right]

Editor Interaction Pane

L: Edit this node, L2: Graph this node, M: Move this node, R: Menu of various operations.

[F1 4 Aug 4:30:40] eof U IN: User Input Query the User

Advanced Simulation Division



D-78



# Company Road March Precedence View

Load

Save

New Goal

Edit Goal

New Procedure

Edit Procedure

Reset Editor

Remember All

Reset Network

Parameters

Goal Node: Company March Lre (Ere-company march lre) Type: Lre Company March Priority: 0

Variable Mappings: Who --> Who Route --> Route Formation --> Nil

Precedence graph for goal Ere-company-road-march

Primitive Subgoal And Node Copy Remember Kill

Procedure View Pop Node Or Node Pop Stack Revert

Goal name: LNL-COMPANY-ROAD-MARCH Goal type: LNL-COMPANY-ATTACK-MARCH

Preconditions:

Achievement-conditions:

Fall-unless-conditions:

Source files: OFFOFFOFF, OFFOFF-MISSIONS, LISP, NEWEST

Description:

Defined by	Role	Number restriction	Value restriction	Default	Description
COMPANY-MARCH-ACTIVITY	WHO	Exactly 1	(ON LNL-COMPANY-MARCH-COMPANY)	none	
COMPANY-MARCH-ACTIVITY	ROUTE	Exactly 1	(A COMPANY-ROUTE)	none	
ERE-COMPANY-APPROACH-MARCH	FORMATION	Exactly 1	(AN APPROACH-FORMATION)	none	general-formation is marked as don't query

Variables (slots from goal or action type)

Editor Interaction Pane

L: Edit this node, L2: Graph this node, M: Move this node, R: Menu of various operations.

Wed 2 Aug 9:53:47 LISP

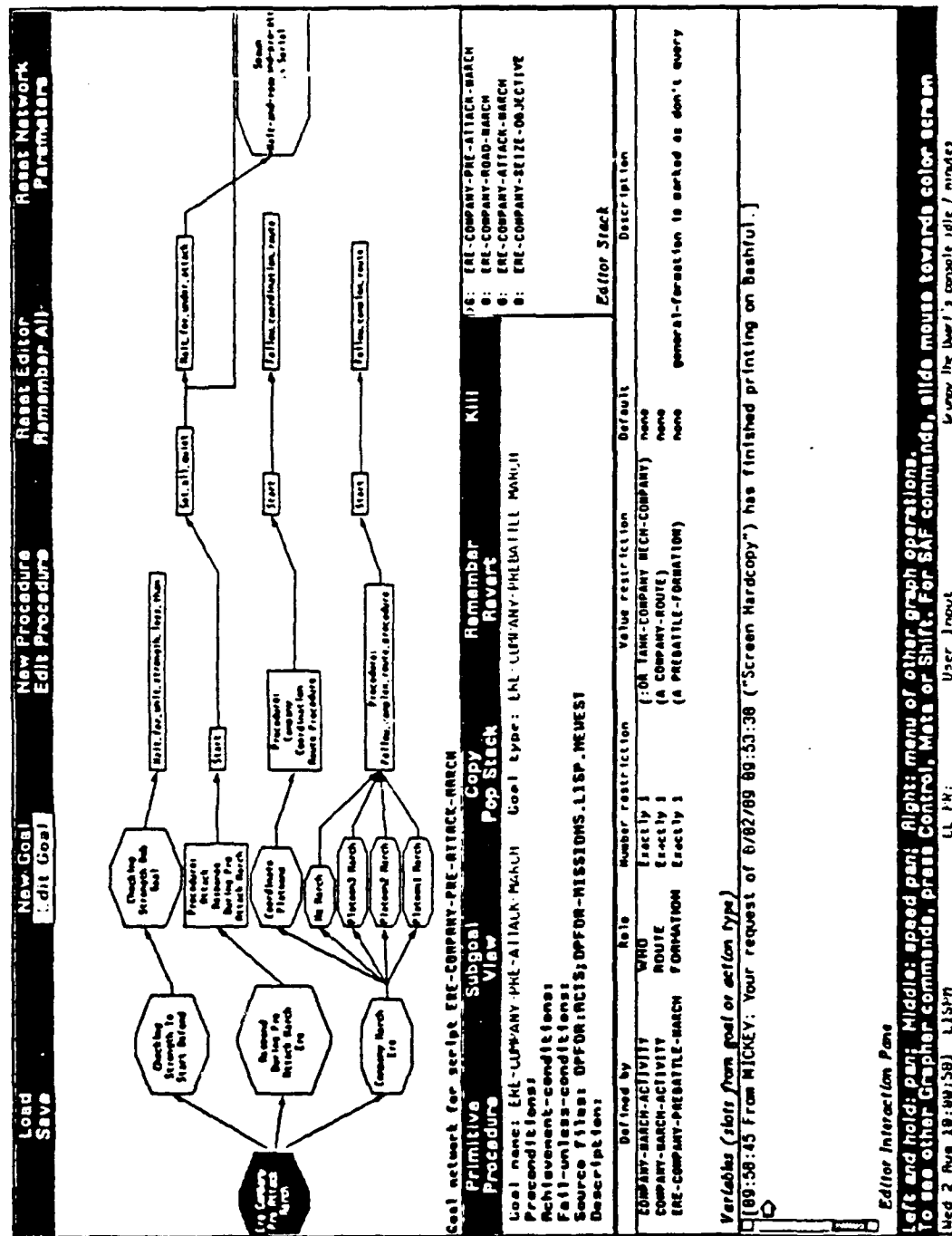
User Input

Copy the Data



Advanced Simulation Division

## Company Pre-Attack March



## **GPP Execution in an Interactive Environment**

- **assigning a mission to a Semi-Automated Force unit involves selecting a mission (goal) and assigning mission parameters**
- **mission behaviors are contingent on events in the simulated world**
- **user interaction to refine behavior will change goal/subgoal parameters, activate alternate paths in the goal tree, or activate new goals**
- **new goals may replace classes of executing goals or execute in parallel with them**



# **Command and Control Process** **The Tank and Mechanized Infantry Team** **FC 71 - 1J**

<u>TROOP-LEADING PROCEDURE</u>	<u>COMMANDER'S ESTIMATE OF THE SITUATION</u>	<u>NETT-T ANALYSIS</u>
RECEIVE THE MISSION		MISSION
ISSUE WARNING ORDER		ENEMY
MAKE A TENTATIVE PLAN	DEVELOP COURSES OF ACTION ANALYSIS OF COURSES OF ACTION	TERRAIN AND WEATHER
INITIATE MOVEMENT/PREPARATION	COMPARE COURSES OF ACTION DECISION	TROOPS AND EQUIPMENT
RECONNOITER		TIME AVAILABLE
COMPLETE PLAN		
ISSUE ORDER (CONVEY COMMANDER'S INTENT)		
SUPERVISE		

Figure 2-1. Command and Control Process.

## **TROOP-LEADING PROCEDURE.**

These are a series of actions used by the company commander for planning, coordinating, executing, and supervising tactical operations. This is a continuous, dynamic process which allows for the most efficient use of available time. All actions within the troop-leading procedure will be accomplished regardless of the amount of time available. The goal is to provide your subordinates the company order within one-third of the available time, thus allowing your subordinates two-thirds of the time for their planning and preparation.

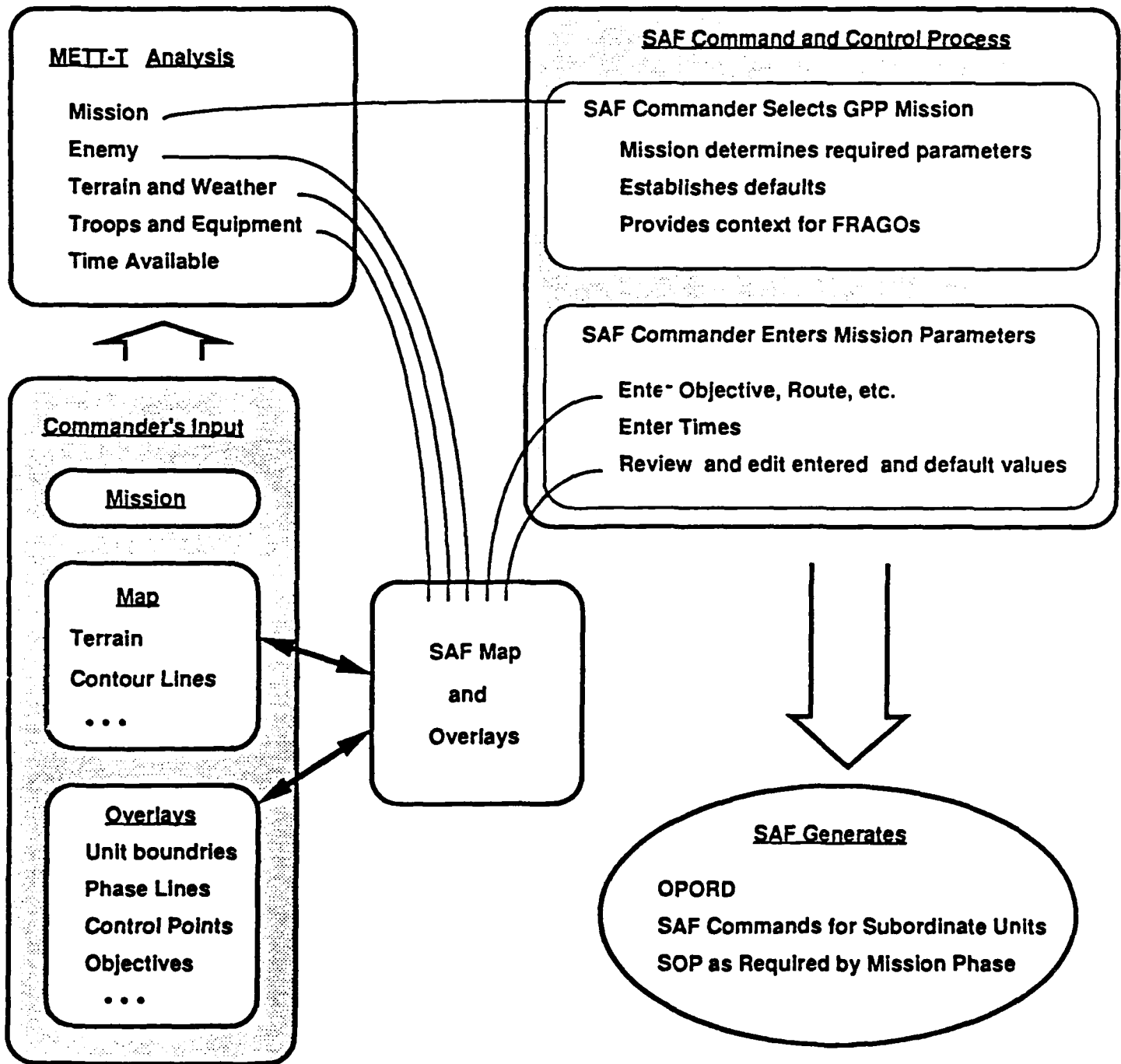
The troop-leading procedure is a continuous process which normally begins upon receipt of a mission and ends when the mission is accomplished.

The actions or steps of the troop-leading procedure are shown in figure 2-1. It is critical to understand that these actions are continuous and are not necessarily accomplished in the order shown.





## SAF Command and Control



# OPORD Text Generation from SAF Mission and Situation

bbn

Simnet Semi-Automated Forces Experimental Workstation

Command Post: D/1 1B

OPERATIONS ORDERS for D/1 1B

OPERATIONS ORDERS FOR D/1 1B

1. SITUATION

D/1 1B is to the south and its mission is to defend Area Of Responsibility ALPHA at 111600 May. D/1 1B and HQC/1 1B are to the southeast. G/2/0 RM, G/2/0 FM, and C/1 1B are to the east.

2. MISSION

D/1 1B's mission is to defend Area Of Responsibility ALPHA at 111625 May. The approach route is ROUTE 2 from ES701011 to ES723000.

3. EXECUTION

a. HQ/D/1 1B

March along Route HQ. First it will change to a line formation at ES701011, then it will go to ES706020, then it will change to a line formation at ES720071, and then it will change to a line formation at ES723000.

b. 1/D/1 1B

March along Route P1. First it will change to a column formation at ES700011, then it will go to ES706020, then it will change to a line formation at ES720071, and then it will change to a line formation at ES724000.

c. 2/D/1 1B

March along Route P2. First it will change to a column formation at ES699012, then it will go to ES706020, then it will change to a line formation at ES720071, and then it will change to a line formation at ES722009.

d. 3/D/1 1B

March along Route P3. First it will change to a column formation at ES702011, then it will go to ES706020, then it will change to a line formation at ES720071, and then it will change to a line formation at ES726007.

Task Order

Guinade

Task Order

Plan View

Tactics

Altitude

OPFOR

Done Save OPORD Read Previous OPORD Print OPORD

Interaction Pane



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## **Goal-Plan-Procedure (GPP) Language**

- **GPP is a plan representation language**
- **basic building blocks are goals, plans and procedures**
- **at this time there is an isomorphism between goals and plans**
- **closely related to ACT1 developed at BBN for work done for NASA Ames and PRS developed at SRL**



## **Goals**

- **state the objective**
- **have preconditions, achievement conditions and failure conditions**
- **goal parameters are defined by an underlying SFL concept**
- **the underlying concepts are used to establish a hierarchy of goals**

## Plans

- a plan is a structure of subgoals and procedures to achieve a goal
- a good plan will deal with contingencies
- *subgoals and procedures are linked by "and", "or" and "pstop" nodes*
- the and/or graph determines execution sequence and success/failure
- sibling nodes will execute in parallel unless restricted by temporal precedence links
- subgoals and procedures take arguments much like lisp functions

## **Procedures**

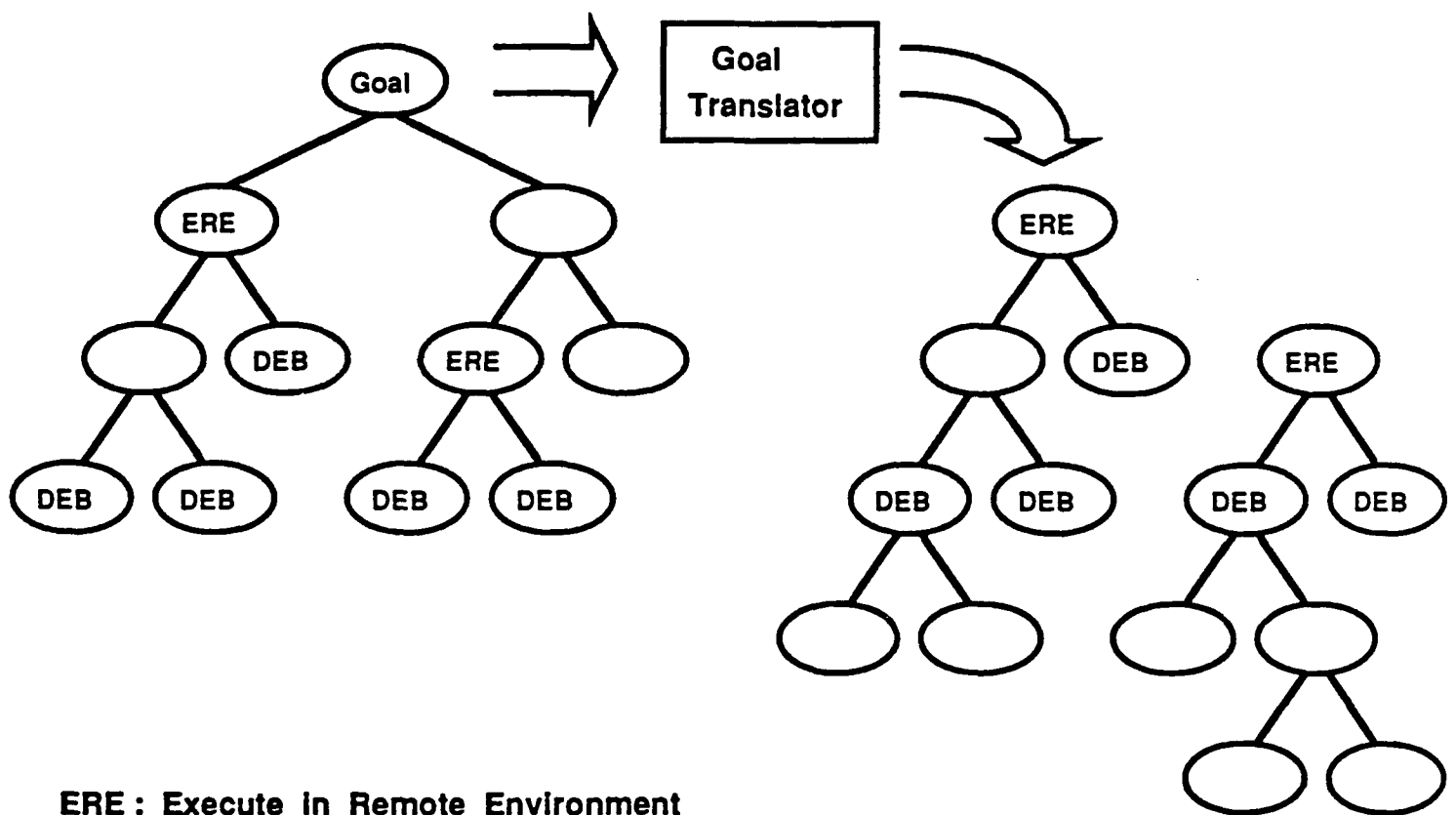
- **provide basic programming constructs that determine agent actions:**
  - **primitive action nodes**
  - **non-primitive action nodes**
  - **control nodes**
  - **wait nodes**
  - **goal spawning nodes**
  - **end nodes returning success/failure**
- **procedure parameters are defined by an underlying SFL concept**



## Goal Execution on Two Hosts

Commander's Workstation  
Lisp

Simulation Host  
"C"



**ERE : Execute in Remote Environment**

**DEB : Don't Execute Below**

## Natural Language Generation Technology bridges the gap between

- The structures appropriate to the reasoning of the expert system and

```
#<COMPANY-WITHDRAW-MARCH 304140017  
((FORMATION NIL)  
(ROUTE . #<COMPANY-RTE 304114775>)  
(REAR-GUARD . PLATOON3)  
(START-TIME . 2820512907)  
(WHO . #<WP-TANK-COMPANY WP-TANK-COMPANY-503  
327027676>)))>
```

- How they can be clearly expressed to the user.

*"A/1 TB withdraws along Route Gamma from ES70886 to ES701808 at 181548 May. The rear guard is 3/A/1 TB."*



**"Natural language generation is a different matter from simply having programs use English....**

**'Template' techniques depend for their effectiveness on a tacit limitation in the number and complexity of the situations in which the program will need to use them.**

**That they have been adequate up to now for expressing what programs have had to say is more of a comment on the simplicity of today's programs than on the capabilities of template-driven generation...."**

**Natural language generation technology must address**

**verstility, varying texts in form and emphasis to meet the enormous range of speaking situations, and**

**creativity, the potential to express any object or relation as a natural language text."**

**David D. McDonald  
"Natural Language Generation"  
AI Encyclopedia**

**Natural Language Generation Technology  
is needed when:**

- **The application task is complex**

***SAF Activities: Planning, C3I, Fire & Manuever,  
Coordination & Synchronizaton.***

- **The domain being modeled is complex**

***SAF Domain: Realistic Battlefield Simulation, large  
numbers of vehicles and units controlled by small  
numbers of commanders***

- **Textual requirements are demanding**

***SAF Textual Requirements: Solder-machine  
communication, Radio simulation, Operations Orders,  
Contents of doctrinal knowledge bases***

## Complexities in Natural Language

one avenue of approach

NOT two avenue of approaches

--> ~~Rather~~ two avenues of approach

A/47 TB marches along Route 3

Not A/47 TB road marches along Route 3

--> Rather A/47 TB conducts a road march along Route 3

A/47 TB is defending in Sector Alpha.

Not A/47 TB is offending in Sector Alpha.

--> Rather A/47 TB conducts an offensive mission in Sector Alpha

# SAF APPLICATIONS OF TEXT GENERATION

## RADIO MESSAGES:

### Spot Reports

*A/74 TB has spotted a platoon of 3 vehicles at E700800.*

### Fuel Status Reports

*A/74 TB's fuel level is 80%.*

### Indirect Fire Reports

*A/74 TB reports 20 rounds of point detonating mortar at ES700800.*

## OPERATIONS ORDERS

### 1. Situation

*C/1 TB is to the east and its mission is to attack objective GAMMA from ES646905 to ES758911 at 141423 Apr. A/1 BT is to the south. B/1TB and HHC/2 are to the east.*

### 2. Mission

*D/1 TB's mission is to defend area of responsibility ALBPH at 111600 May. The approach route is Route 2 from ES701811 to ES725888.*

### 3. Execution

...

# **SPOKESMAN**

## **Natural Language Generation System**

### **COMPONENTS**

#### **TEXT PLANNER:**

**Selects information to be communicated**

**Determines perspectives and rhetorical organization**

**Chooses the linguistics resources (words, syntactic classes)**

Developed at BBN to meet the demands of DARPA's military planning and simulation systems, such as the AirLand Battle Management Program (ALBM) and Semi-Automated Forces (SAF) which have complex world models and strict textual requirements.

#### **LINGUISTIC REALIZATION COMPONENT--Mumble-86:**

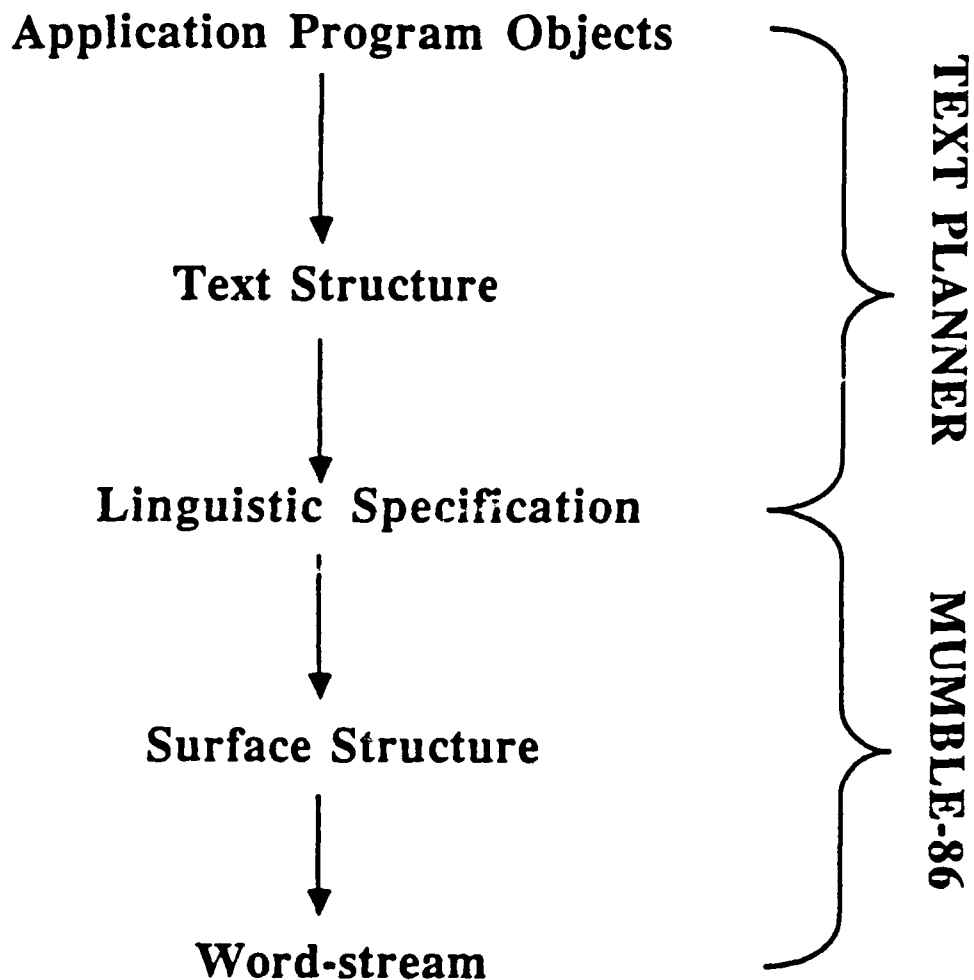
**Carries out the text planner's specifications to produce the text**

**Ensures the text is grammatical**

**Handles all syntactic and morphological decision making**

Developed under DARPA's Strategic Computing Program at MIT and the University of Massachusetts

# **SPOKESMAN's Components and Levels of Representation**



## DATA DIRECTED APPROACH TO NATURAL LANGUAGE GENERATION

**DATA DIRECTED:** The *content* of the utterance is provided by the *application program*

- **More efficient at run time:** specification of content is a by-product of the application program.
- **Takes advantage of the structures in the expert system** which directly reflect the experts' high level view of the information.
- **More efficient to build:** uses domain model from the application program, rather than building a separate one for the generator.

## **Terrain Representation and Reasoning**

### **Requirements**

- **Map-like display.**
- **Support terrain reasoning**
  - **Object oriented.**
  - **Network based.**
- **Fast drawing time.**
- **Dynamic.**
  
- **Cannot use polygonal representation used by SIMNET CIGs.**





## **Terrain Representation and Reasoning**

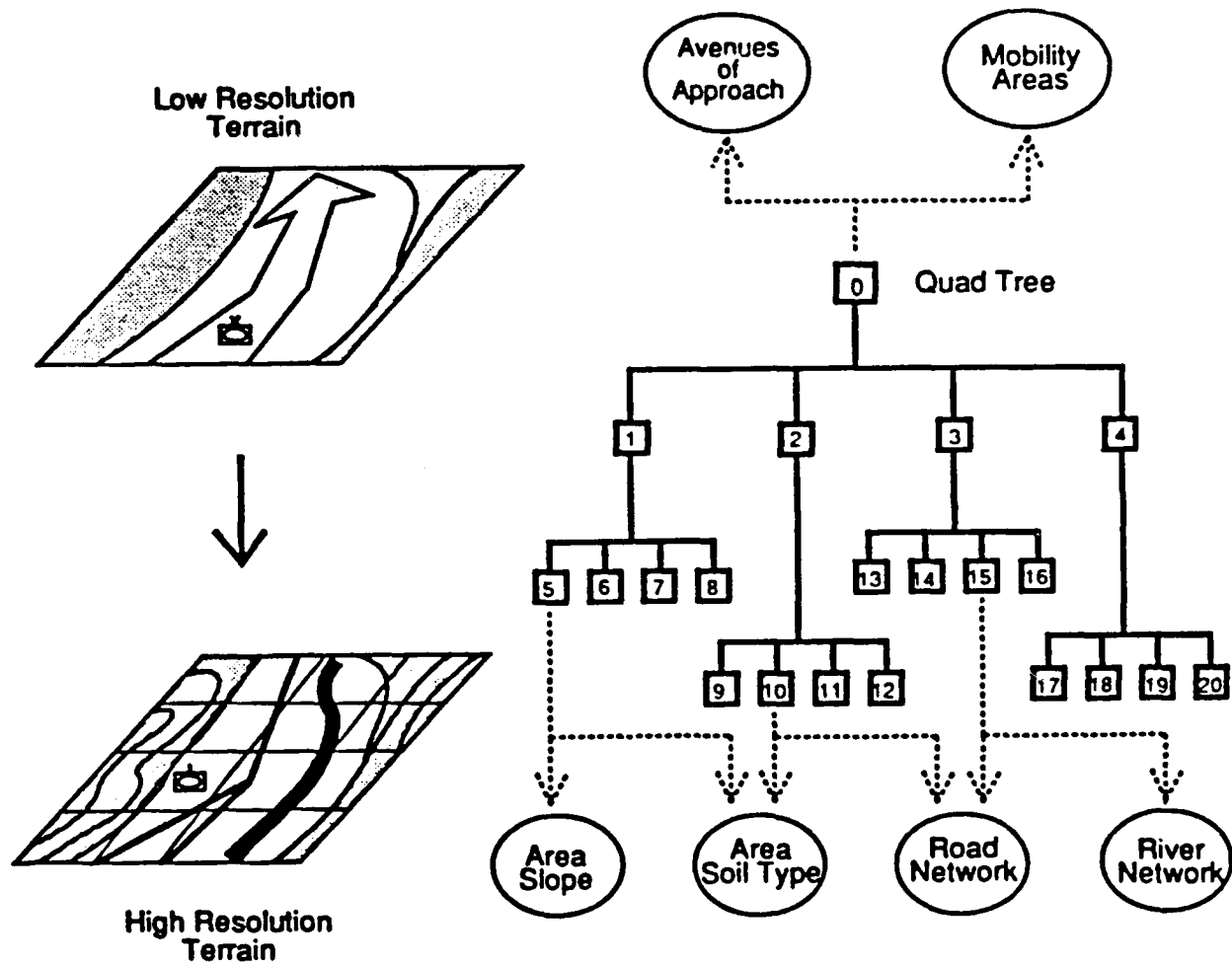
### **Representation**

- **Diversified quadtree for spatial relationships.**
  - **Terrain features stored in arrays as objects.**
  - **Quadtree nodes contain indices into arrays.**
  - **Populated at all levels down to 2500 meter square patches.**
- **Variable resolution for terrain reasoning.**
  - **Same objects stored differently at different levels**
  - **forest → treelines → trees**
- **Vertical scaling by using hierarchies of granular maps.**



# Terrain Representation and Reasoning

## Diversified Quadtree



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## **Terrain Representation and Reasoning**

### **Terrain Features**

- **Road network**
  - **width, intersections, distances**
  - **bridges**
- **River network**
  - **width, intersections, distances**
- **Water bodies**
  - **boundary vectors, polygons (drawing)**
- **Treelines and canopies**
  - **boundary vectors, heights**
- **Buildings**
  - **bounding volumes, height**
- **Contours**  
  
**vectors, elevation**



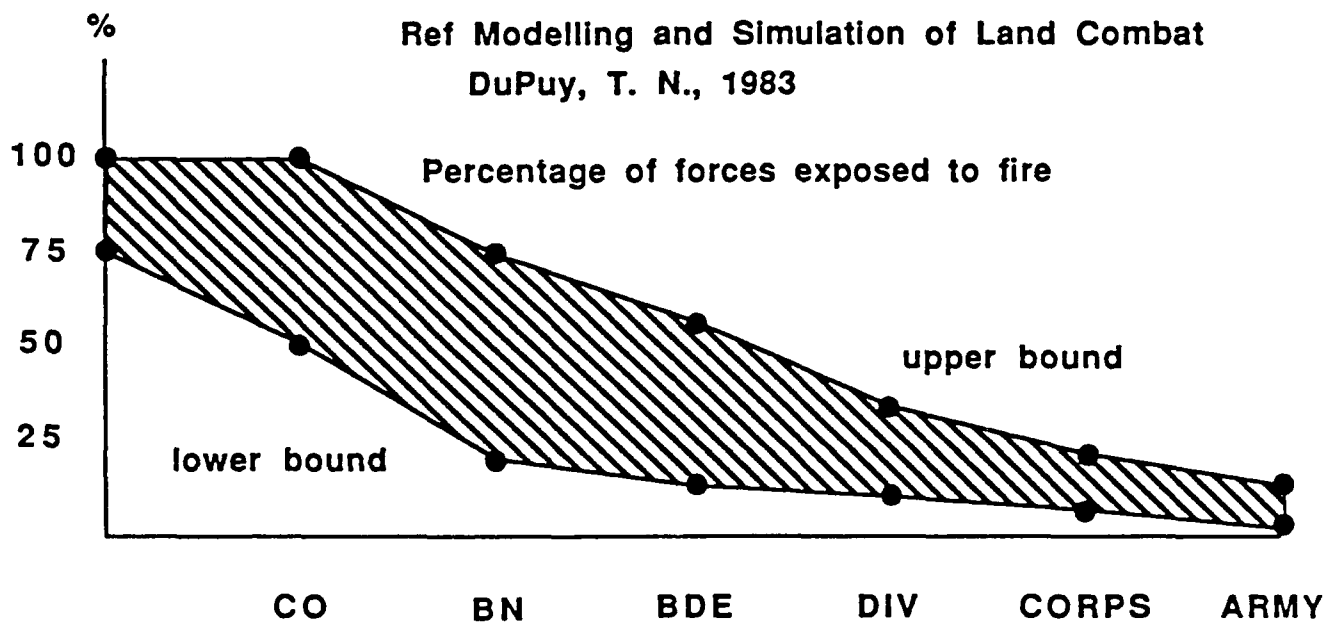
## **Semi-Automated Forces**

### **The Combinatorics of Vertical Scaling**

- Orders of magnitude Increase in numbers of BOS, terrain size, time.
- There exist three major challenges
  - reduce computation required to handle BOS interactions from  $N^2$  to linear.
  - reduce computation required per individual BOS to less than linear.
  - provide minimally manned SAF command hierarchy with command tools to handle increase in assets.
- Do so while maintaining physical integrity at the BOS level.



**Activity Levels of BOS  
Depends on  
Tactical Context**



- As scale of battle increases, percentage of BOS exposed to fire at any one time decreases.
- Generalized observation is that as scale of battle increases percentage of BOS involved in specific situations at any one time decreases.
- Simulate BOS to a degree of fidelity suitable to the context.



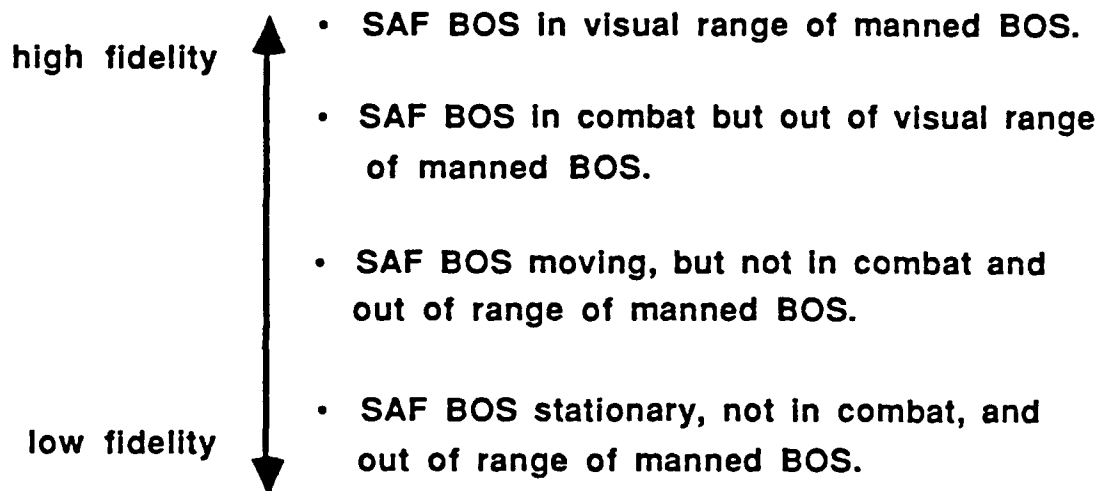
**Dynamic Fidelity Simulation  
of  
SAF BOS**

- **Maintain physical existence of SAF BOS at all times.**
- **Use variable simulation tick rate to modify simulation fidelity.**
- **Higher tick rate gives higher simulation fidelity.**
- **Tactics equivalent of the dead reckoning model.**
- **Tactical behavior divergence replaces dynamics divergence.**



## Context Dependent Fidelity

- A spectrum of fidelity requirements exists, for example



- SAF BOS in range of a sensor which relays information directly back to a human. Simulation fidelity depends on sensor resolution.
- The above example covers the basic tasks of move, shoot, communicate, see.
- Can tailor simulation fidelity to contexts of interest to user, i.e. can concentrate on BFA of choice.



## Feasibility Calculation Example

- Single SAF BOS at maximum simulation fidelity is the baseline.
- Four simulation fidelity buckets: 1, 1/5, 1/25, 1/125
- Consider a 5000 vehicle blue div versus a 15000 vehicle red CAA.

	Fidelity Bucket				
	1	1/5	1/25	1/125	
Div 5000	40%	30%	20%	10%	2344
	2000	1500	1000	500	
	2000	300	40	4	
CAA 15000	25%	25%	25%	25%	4680
	3750	3750	3750	3750	
	3750	750	150	30	
20000					7024

- Approximately 65% saving over linear fixed full fidelity.

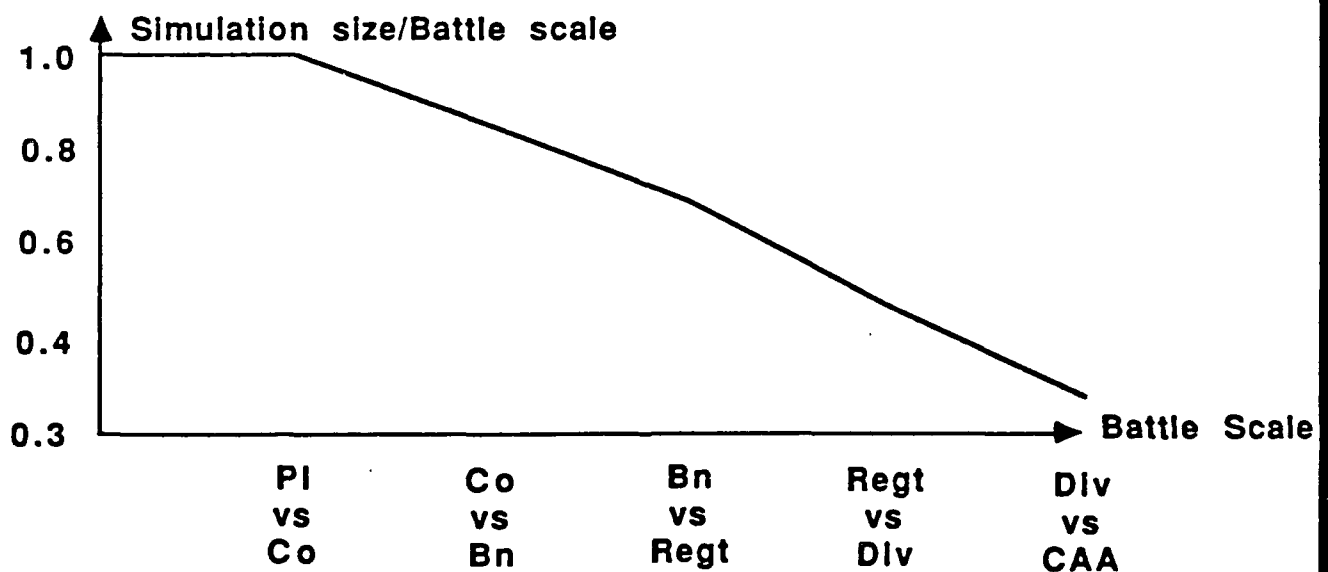




**Reduce Simulation Requirements  
per BOS  
to less than Linear**

- Assume conservative size of unit is four times size of subordinate.
- Assume conservative distribution of unit BOS over simulation buckets.

	Simulation Fidelity			
	1	1/5	1/25	1/125
Co	100	0	0	0
Bn	75	25	0	0
Regt	60	30	10	0
Div	40	30	20	10
CAA	25	25	25	25



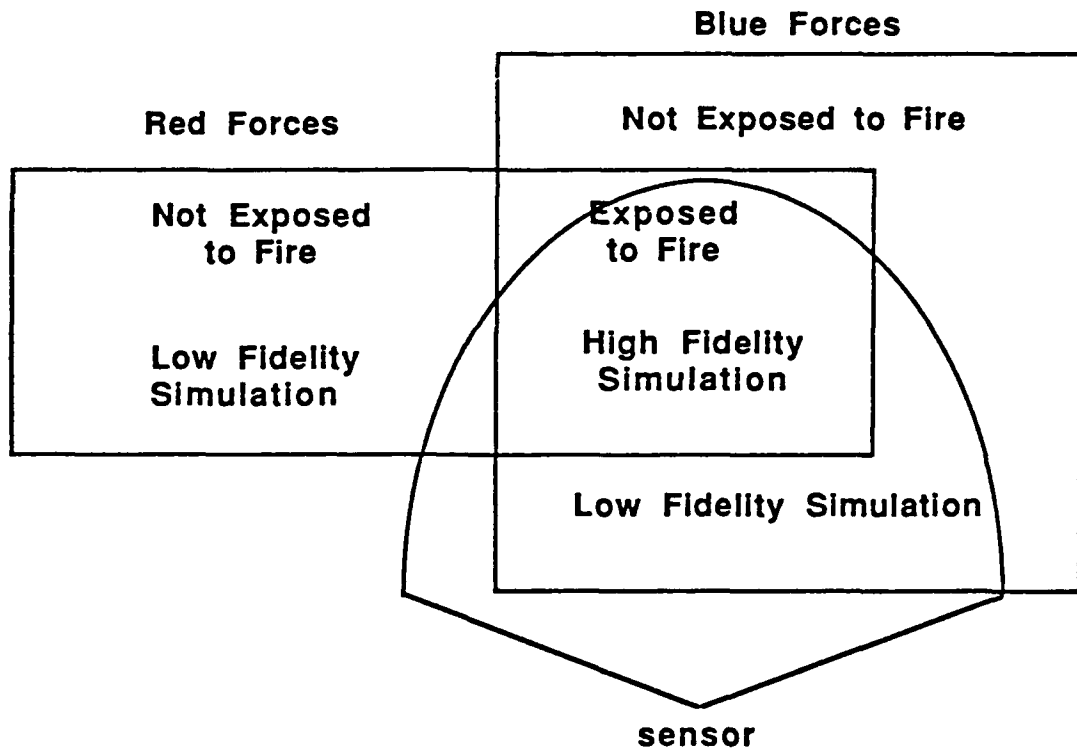
## **After Action Review**

- **AAR Insertion In a taped battle will lead to human eyeballs In low simulation fidelity areas.**
- **The AAR system must contain SAF code to Integrate over long tick rates and produce intermediate updates.  
A smoothing algorithm.**
  - **Use stored future ticks of the BOS.**
  - **Use SAF unit missions**
- **SAF unit missions must be broadcast over the SIMNET LAN.**
  - **AAR can now analyze command decisions,  
not just BOS behavior.**



## Surge Conditions

- Surge conditions can be caused by high resolution large footprint sensors.



- Use smoothing algorithms similar to AAR.



## **Dynamic Fidelity Simulation**

### **Conclusion**

- **Tactical context drives simulation fidelity.**
- **Can tailor large scale simulation to concentrate simulations resources on BFA of interest to user.**
- **Simulation fidelity varied by tick rate at the BOS level.**
- **Simulation assets per simulated BOS less than linear with battle scale.**



## **Situation Prediction**

- **Must be able to predict ahead of SIMNET time for tactical situations**
  - **Critical tactical decisions for software subordinates to be made by commander in downward control mode.**
  - **Software subordinates must be able to plan (under supervisory control of human commander).**
  - **Detect changes in tactical context which will drive changes in fidelity of the BOS simulation.**
- **Use a fast look-ahead aggregated combat simulator driven by SAF missions (Tactical Action Representation Language) and based on SIMNET situation as starting scenario.**
- **Use DARPA funded ALBM heuristic combat evaluator (HCE) (developed by BBN's SIMNET team) as starting point (shared ideas and development techniques lead to fast utilization).**



## Fast Look-Ahead Wargamer

